Guide to Ultrasonic Inspection of Fasteners

Part No. 021-002-175
Rev. B

©2003 STRESSTEL
50 Industrial Park Road
Lewistown, PA 17044
Phone (866)243-2638
Fax (717) 242-2606
www.stresstel.com

Guide to Ultrasonic Inspection of Fasteners

STRESSTEL
ULTRASONIC TESTING EQUIPMENT

Copyright 2003 StressTel

Important Notice

The following information must be read and understood by any user of a StressTel measurement instrument. Failure to follow these instructions can lead to errors in stress measurements or other test results. Decisions based on erroneous results can, in turn, lead to property damage, personal injury or death. StressTel assumes no responsibility for the improper or incorrect use of this instrument.

General Warnings

Proper use of ultrasonic test equipment requires three essential elements:

- Selection of the correct test equipment
- Knowledge of the specific “test application requirements”
- Training on the part of the instrument operator

This operating manual provides instruction in the basic set-up and operation of the StressTel BoltMike III measurement instrument. There are, however, additional factors which affect the use of ultrasonic test equipment. Specific information regarding these additional factors is beyond the scope of this manual. The operator should refer to textbooks on the subject of ultrasonic testing for more detailed information.

Operator Training

Read the information in this manual prior to use of a StressTel instrument. Failure to read and understand the following information could cause errors to occur during use of the instrument. Failure to follow these instructions can lead to error in stress measurement or other test results. Decisions based on erroneous results can, in turn, lead to property damage, personal injury or death.

Operators must receive adequate training before using ultrasonic test equipment. Operators must be trained in general ultrasonic testing procedures and in the set-up required before conducting a particular test. Operators must understand:

- Soundwave propagation theory
- Effects of the velocity at which sound moves through the test material
- Behavior of the sound wave
- Which areas are covered by the sound beam

More specific information about operator training, qualification, certification and test specifications is available from various technical societies, industry groups, and government agencies.

Testing Limitations

Information collected as a result of ultrasonic testing represents only the condition of test-piece material that is exposed to the sound beam. Operators must exercise great caution in making inferences about the test material not directly exposed to the instrument’s sound beam. When a less-then-complete inspection is to be performed, the operator must be shown the specific areas to inspect. Inferences about the condition of areas not inspected, based on data from evaluated areas, should only be attempted by personnel fully trained in applicable techniques of statistical analysis.

Sound beams reflect from the first interior surface encountered. Operators must take steps to ensure that the entire thickness of the test material is being examined.

Calibrating the instrument/transducer combination is particularly important when the test piece is being ultrasonically tested for the first time or in any case where the history of the test piece is unknown.

Transducer Selection

The transducer used in testing must be in good condition without noticeable wear of its contact surface. Badly worn transducers will have a reduced effective measuring range. The temperature of the material to be tested must be within the transducer’s temperature range. If the transducer shows any signs of wear it should be replaced.

- Soundwave propagation theory
- Effects of the velocity at which sound moves through the test material
- Behavior of the sound wave
- Which areas are covered by the sound beam

More specific information about operator training, qualification, certification and test specifications is available from various technical societies, industry groups, and government agencies.

Testing Limitations

Information collected as a result of ultrasonic testing represents only the condition of test-piece material that is exposed to the sound beam. Operators must exercise great caution in making inferences about the test material not directly exposed to the instrument's sound beam. When a less-then-complete inspection is to be performed, the operator must be shown the specific areas to inspect. Inferences about the condition of areas not inspected, based on data from evaluated areas, should only be attempted by personnel fully trained in applicable techniques of statistical analysis.

Sound beams reflect from the first interior surface encountered. Operators must take steps to ensure that the entire thickness of the test material is being examined.

Calibrating the instrument/transducer combination is particularly important when the test piece is being ultrasonically tested for the first time or in any case where the history of the test piece is unknown.

Transducer Selection

The transducer used in testing must be in good condition without noticeable wear of its contact surface. Badly worn transducers will have a reduced effective measuring range. The temperature of the material to be tested must be within the transducer's temperature range. If the transducer shows any signs of wear it should be replaced.

Contents

Chapter 1: Ultrasonic Measurement of Fasteners 1

1.1 Important Concepts 1
1.1.1 Acoustic Velocity 1
1.1.2 The Use of Ultrasound 1
1.1.3 Initial Pulse and Multi-Echo Measurement Modes 2
1.1.4 Time of Flight and Ultrasonic Length .. 2
1.1.5 Tensile Load 3
1.1.6 Stress 4
1.1.7 Elongation 4
1.1.8 Modulus of Elasticity (Eo) 4
1.1.9 Stress Factor (K) 5
1.1.10 Temperature Coefficient (Cp) 6
1.1.11 Calibration-Group Correction Factors — Stress Ratio and Offset 6
1.1.12 Fastener Geometry 6
1.2 Principles of BoltMike Operation 7
1.3 Practical Limitations Of Ultrasonic Measurement 8
1.3.1 Material Compatible with Ultrasonic Inspection 8
1.3.2 Significant Fastener Stretch 8
1.3.3 Fastener End-Surface Configuration . 9
1.3.4 The Limitations of I.P. and M.E. Measurement Modes 9

Chapter 2: Fastener Preparation 11

2.1 Fastener End-Surface Machining 11
2.2 Methods Of Transducer Placement 12
2.2.1 Practical Methods 12
2.2.2 Fixtures for Non-Magnetic Fasteners 14

Chapter 3: Transducer Selection 15

3.1 General Acceptability 15
3.2 Transducer Frequency 15
3.3 Transducer Diameter 15
Purpose of Instrument and Transducer Zeroing 15

Chapter 4: Temperature Compensation 17

4.1 Measuring Fastener Temperature 17
4.2 Limits of Accurate Temperature Measurement 17
4.3 Adjusting the Temperature Coefficient 18

Chapter 5: Selecting Phase 19

Chapter 6: Fastener Geometry 21

6.1 Approximate Length 21
6.2 Determining Effective Length 21
6.3 Fastener Cross-Sectional Area 24

Chapter 7: Material Constants 25

7.1 Standard Material Constants 25
7.2 Custom Material Constants 25
7.3 Selecting a Material Constant 25
7.4 Material Variations 26

Chapter 8: BoltMike Formulas 27

Appendix: Tabular Data 29

Chapter 1: Ultrasonic Measurement of Fasteners

When threaded fastening systems (comprised of a bolt or stud and a nut) are tightened, the threaded fastener is said to be tensioned. The tensioning force in the fastener (identified in the BoltMike as its load) is equal to the fastening system's clamping force.

The BoltMike determines the load on a fastener by measuring the amount of time it takes for a sound wave to travel along a fastener's length, before and after a tensioning force is applied to the fastener. The fastener material's acoustic velocity, together with difference in the measured times, allows the instrument to calculate the change in fastener length under the tensile load. Provided the fastener's dimensional and material properties are known, and the constants that represent the material properties are entered into the instrument, the BoltMike will calculate the load and stress present when the fastener is in its tensioned state.

1.1 Important Concepts

To best understand exactly how ultrasonic sound waves are used to determine loads, stress, and elongation of threaded-fasteners, it is necessary that you understand the concepts described in this section. Chapter 8 lists the actual formulas used by the BoltMike to calculate many of the quantities described below.

1.1.1 Acoustic Velocity

Applying a large electric pulse to a piezoelectric element in a transducer creates an ultrasonic shock wave. This type of shock wave, known as longitudinal wave, travels through a fastener at a speed equal to the fastener material's acoustic velocity. A material's acoustic velocity represents the speed with which sound moves through it. All materials have a representative acoustic velocity but true velocity can vary from one sample to another (of the same material type) and even throughout the material in a particular sample. It is important to realize that the actual acoustic velocity is not truly a constant. Instead, it varies between fasteners of like material, even when the fastener's material composition is tightly controlled.

1.1.2 The Use of Ultrasound

The ultrasonic wave is transmitted from a transducer into the end of a fastener. When the ultrasonic wave encounters an abrupt change in density, such as the end of the fastener, most of the wave reflects. This reflection travels back the length of the fastener and back into the transducer. When the shock wave re-enters the piezoelectric element a small electrical signal is produced. This signal is represented on the BoltMike's display panel by the triggering of a measurement gate. This signal is used by the BoltMike to indicate the returning wave. (Figure 1-1)

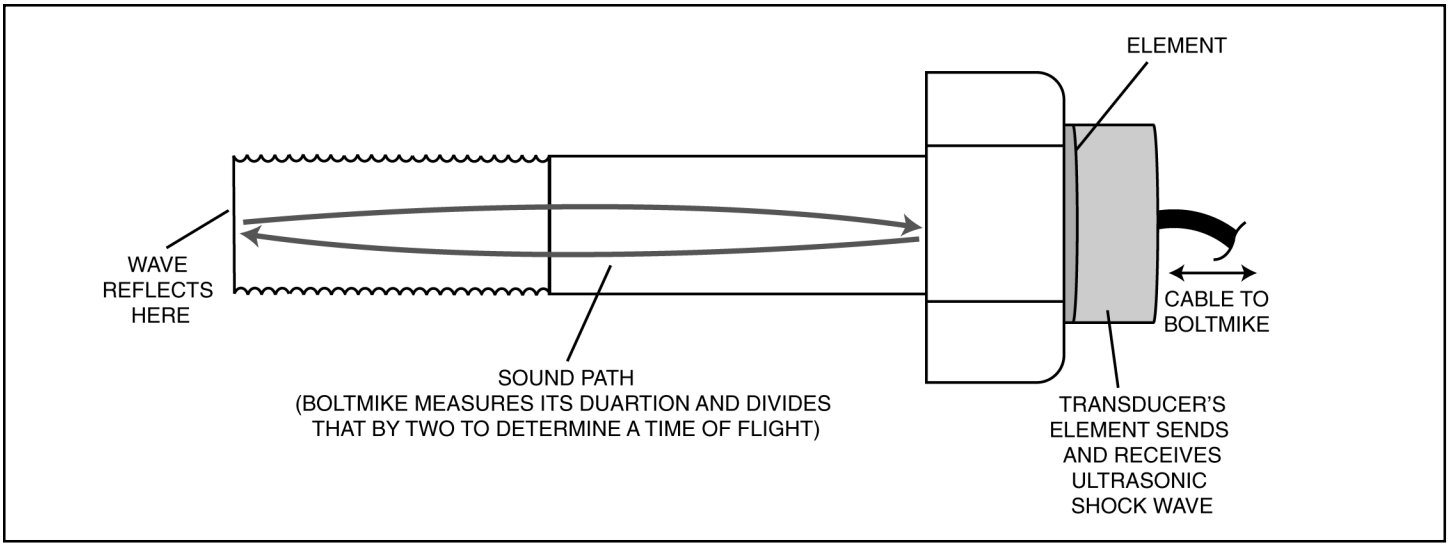
ELEMENT
WAVE REFLECTS HERE
CABLE TO BOLTMIKE
SOUND PATH
(BOLTMIKE MEASURES ITS DUARTION AND DIVIDES THAT BY TWO TO DETERMINE A TIME OF FLIGHT)
TRANSDUCER'S ELEMENT SENDS AND RECEIVES ULTRASONIC SHOCK WAVE

FIGURE 1-1—The BoltMike determines the length of a fastener by measuring how long it takes for sound to travel its length.

1.1.3 Initial Pulse and Multi-Echo Measurement Modes

The BoltMike III can be operated in one of two ultrasonic measurement modes: initial pulse (I.P.) and multi-echo (M.E.). In I.P. mode, as illustrated in Figure 1-2A, a sound pulse is sent through the fastener. The BoltMike's triggering gate is positioned (based on the user-inputted value of the fastener's approximate length) to detect this sound pulse's first returning echo. The BoltMike measures the time duration between transmitting and receiving the sound pulse, and uses this value as the basis for its calculations.

In M.E. measurement mode, a sound pulse is again transmitted into the fastener. This time, however, the BoltMike utilizes two triggering gates. These gates are positioned so that the first returning echo triggers the first gate, and the second returning echo triggers the second gate. The gates are again positioned based on the user-inputted value of the fastener's approximate length. In this mode the BoltMike measures the time duration between triggering of the two gates by two consecutive echoes. It is critical, however, that similar features on the two consecutive packets be used to trigger the gates.

An advantage of operating in M.E. mode is that all measurements are taken between the first and second returning echoes. This means that variations in transducer-to-fastener coupling (caused, for instance, by varying couplant thickness) and instrument zeroing are factored out of the BoltMike's measurement. This is shown in Figure 1-2B.

1.1.4 Time of Flight and Ultrasonic Length

The elapsed time between transmitting and receiving the shock wave is known as the sound-path duration. Of course, as shown in Figure 1-1, the sound-path duration actually represents the elapsed time taken by the

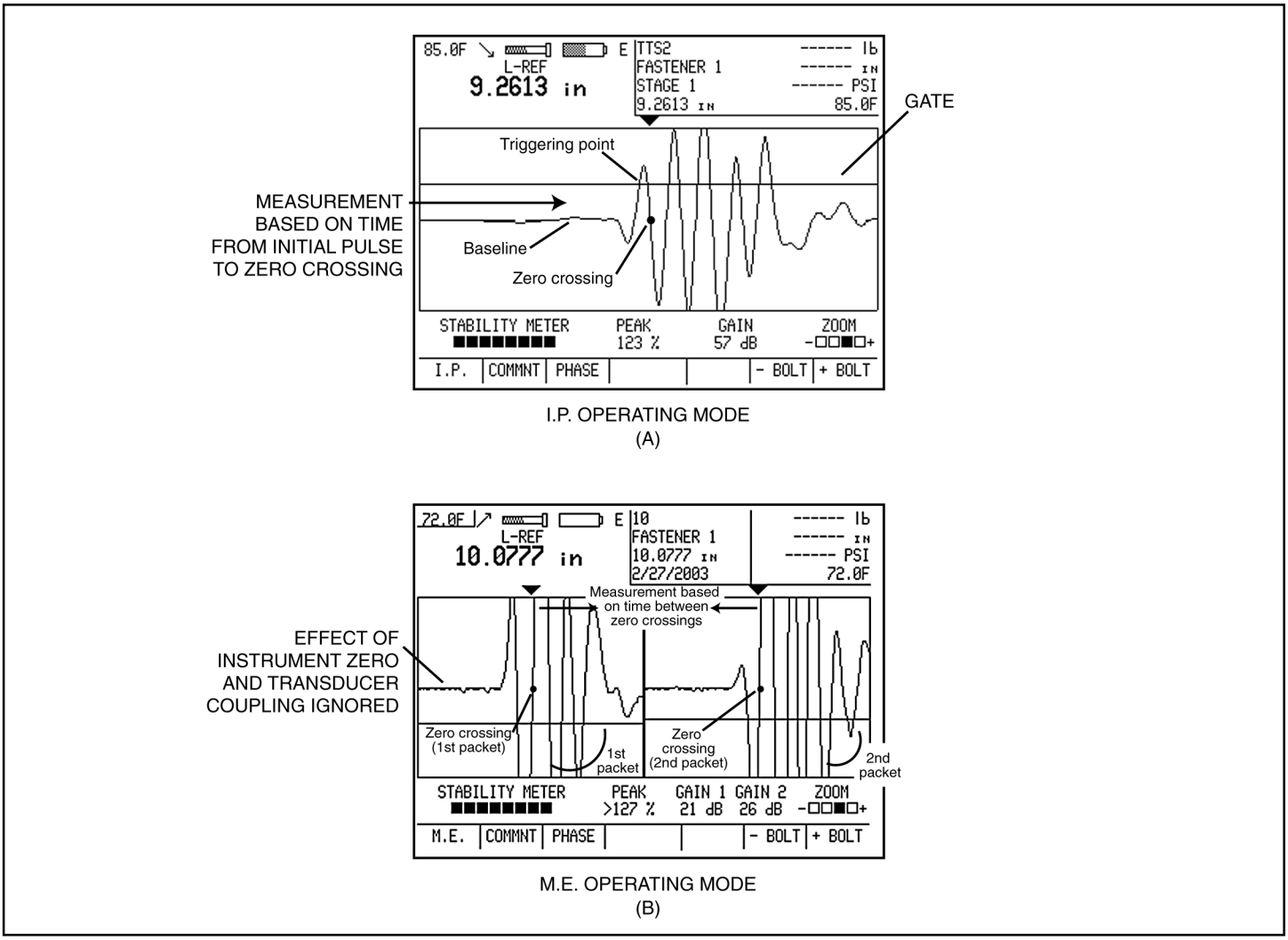

FIGURE 1-2—In Initial Pulse (I.P.) mode, the BoltMike measures the time to the first gate triggering. In Multi-Echo mode the time between two consecutive gate crossings is measured.

wave to travel the length of the fastener two times. This duration is divided by two to find the time of flight (TOF), which represents the time it takes for the shock wave to travel once down the length of the fastener. The BoltMike then determines the *ultrasonic length* by first correcting the measured TOF for any changes in temperature, and then multiplying by the fastener's acoustic velocity. Acoustic velocity is represented in the BoltMike with the variable V and is determined by the fastener's material type). Further corrections (as described below) are then made to this ultrasonic length to determine a measured physical length.

Because the actual acoustic velocity is not truly a constant, the uncorrected ultrasonic length is not exactly the same as the physically measured length. Even if two identical fasteners' physical lengths are very tightly controlled, the measured time of flight through each fastener may vary by as much as one percent. Because of this variability, the *change* in measured time of flight (recorded before and after each fastener is tensioned) must be used to accurately determine the tensile stress in a fastener. As you will learn shortly, acoustic velocity also varies with factors other than material type including stress (sections 1.1.9) and temperature (section 1.1.10). For this reason the BoltMike incorporates logic to compensate for these effects on ultrasonic length.

1.1.5 Tensile Load

As you may be aware, when the nut in a threaded fastening system is tightened, the clamping force the fastening system (nut and bolt or stud) places on the joint is equal to the tensile load placed on the fastener. This effect is shown in Figure 1-3. The BoltMike calculates Load (L) by first determining tensile stress (as described below), then multiplying by the fastener's cross-sectional area.

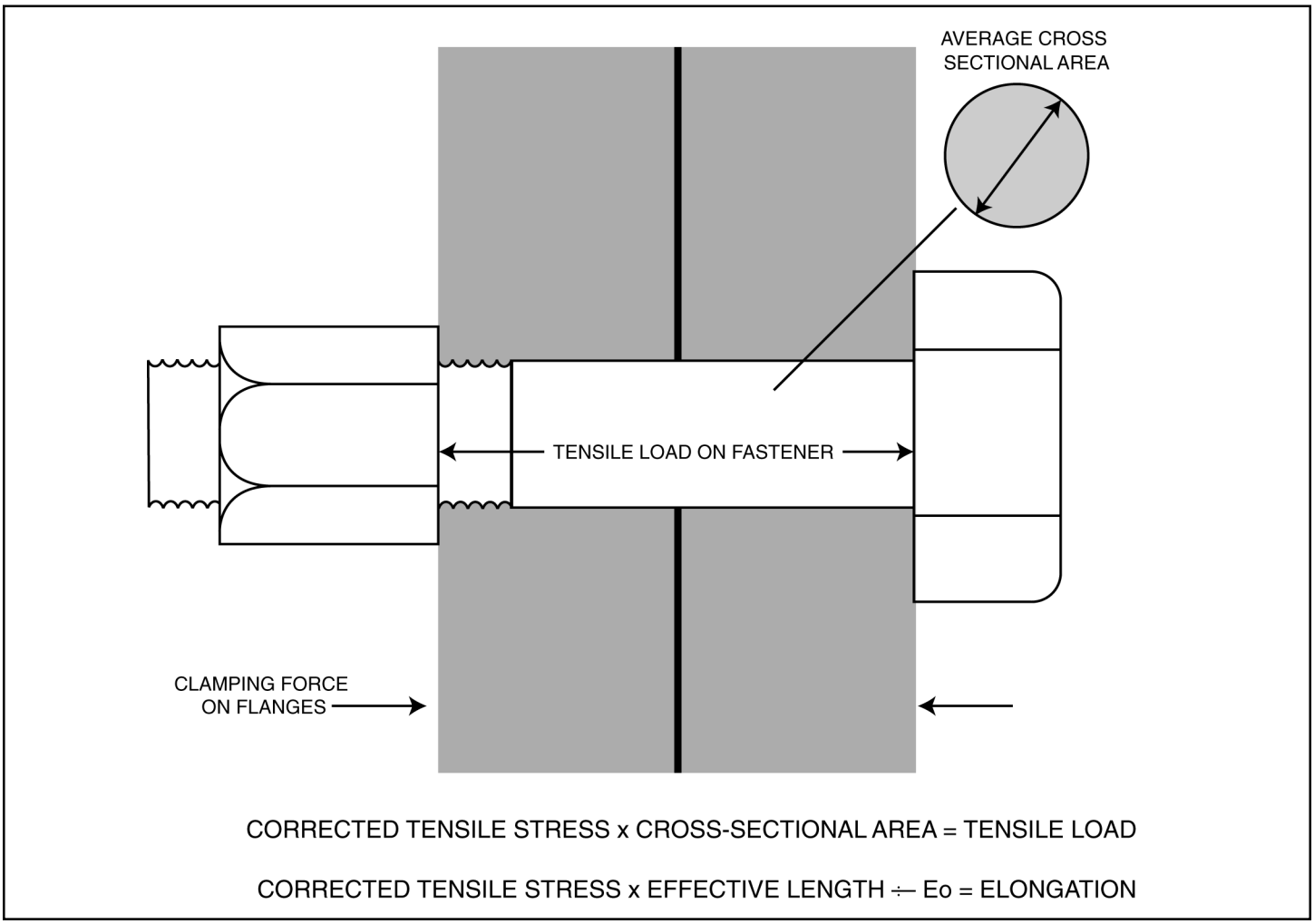
AVERAGE CROSS
SECTIONAL AREA
TENSILE LOAD ON FASTENER
CLAMPING FORCE
ON FLANGES
CORRECTED TENSILE STRESS x CROSS-SECTIONAL AREA = TENSILE LOAD
CORRECTED TENSILE STRESS x EFFECTIVE LENGTH ÷ Eo = ELONGATION

FIGURE 1-3—As the threaded fastening system is tightened, tensile loads are applied to the bolt or stud and elongation occurs.

1.1.6 Stress

Stress occurs when load is applied to a fastener. When a tensile load (like the one shown in Figure 1-3) is applied to a fastener, the tensile stress is equal to the tensile load divided by the fastener's average cross-sectional area (see the Appendix for average cross-sectional areas). The BoltMike calculates tensile stress in units of pounds per square inch (psi) or mega Pascal (MPa). This calculation is performed using the change in ultrasonic length, the effective length, acoustic velocity (described in section 1.1.1), the material's stress factor (a property that is described below), and stress compensation parameters known as Stress Ratio and Stress Offset. These are instrument correction parameters that are described in section 1.1.11.

1.1.7 Elongation

As a tensile load is applied, a fastener stretches in the same way a spring would. The amount of stretch, known as *elongation*, is proportional to the tensile load as long as the load is within the fastener's working range (which means at loads that are less than the fastener's yield strength – a term we'll describe shortly). Using the effective length, the material's modulus of elasticity, and the calculated value for corrected stress the BoltMike calculates elongation. (Figure 1-3)

1.1.8 Modulus of Elasticity (Eo)

When a fastener is loaded with a tensile force, its length increases. As long as the loading does not approach the fastener's *yield strength* (defined as the loading point beyond which any change in material shape is not completely reversible), the relationship between the tensile stress and elongation is linear. By this we mean that if the stress level increases by a factor of two, the amount of elongation also increases by a factor of two. For load levels in the fastener's elastic region (meaning that the loads are less than the yield strength of the fastener), the relationship between stress and elongation is described by a material constant known as the *modulus of elasticity*. The variable Eo in the BoltMike represents the modulus of elasticity. The concepts of tensile stress, elongation, modulus of elasticity, and yield strength are illustrated in Figure 1-4.

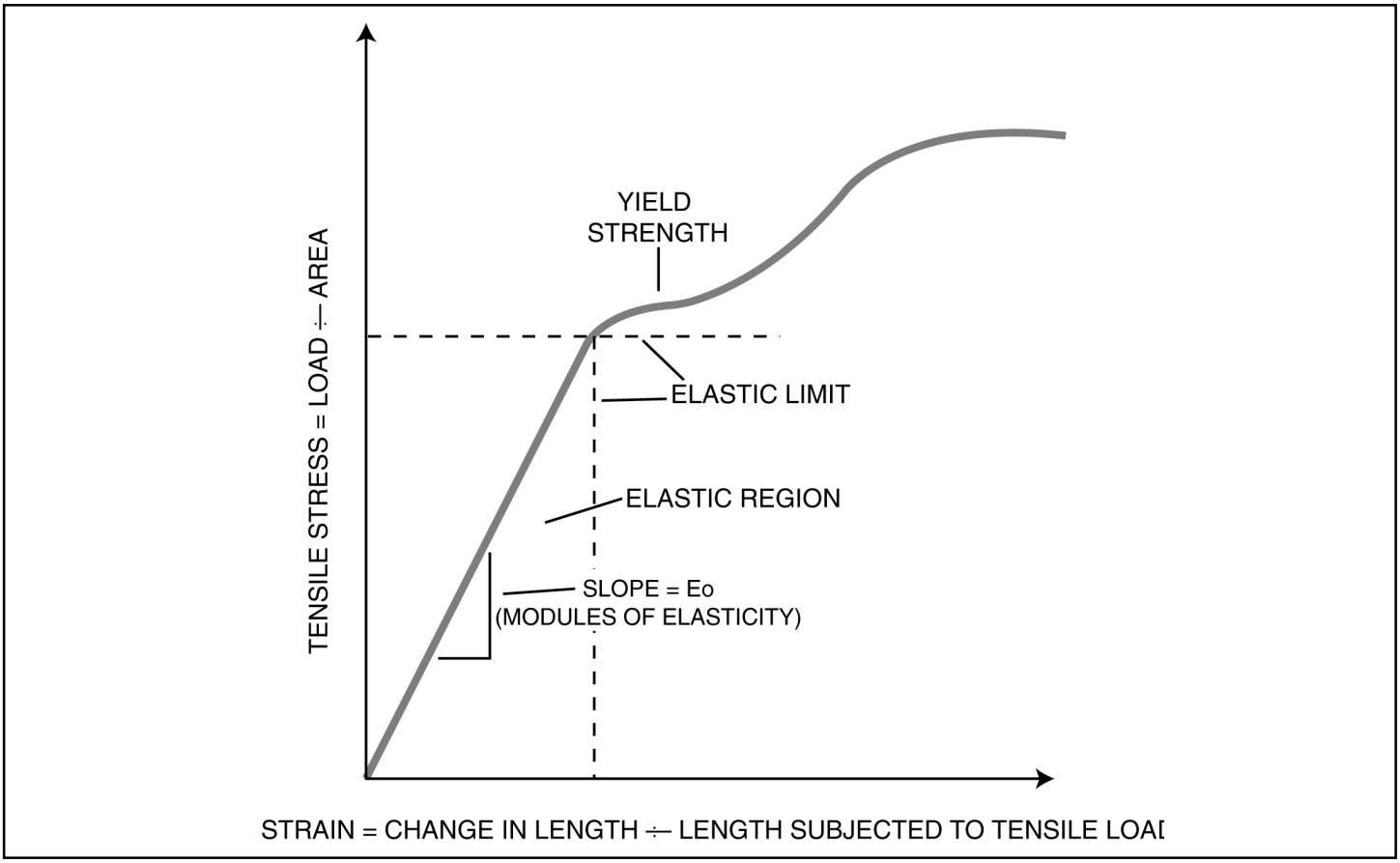

FIGURE 1-4—This graph shows the relationship between tensile stress and elongation in a fastener. The material's modulus of elasticity equals the slope of the straight portion of this curve (this area is known as the material's elastic region). The point at the top of the curve, where it is no longer linear, represents the material's yield strength. Note that the graph actually plots stress verses strain. Strain is simply the amount of elongation, divided by the original length of the stressed section.

1.1.9 Stress Factor (K)

The velocity at which a longitudinal wave moves through an object is affected by stress. When a fastener is stretched there are two influences on its ultrasonic length (as determined by multiplying the sound wave's time of flight by the constant value of acoustic velocity). First, the length of material through which the sound must travel increases. Also, the fastener's actual acoustic velocity decreases as stress increases. In other words, even when the stretching effect on the fastener's physical length is ignored, tensile stress leads to an increase in the fastener's ultrasonic length. In the BoltMike, a material constant known as the *Stress Factor (K)* compensates for the effect stress has on the fastener's actual acoustic velocity.

A great deal of confusion surrounds this effect. Consider the example shown in Figure 1-5 as you read the following description. In Figure 1-5A, no load is applied to the fastener when the reference ultrasonic length (UL1) is recorded. In Figure 1-5B, a load is applied and a new ultrasonic length (UL2) is recorded. Note that Figure 1-5A and B also identify the physical length when unloaded (Physical Length 1) and loaded (Physical Length 2). The actual physical elongation of the fastener equals Physical Length 1 – Physical Length 2. The difference between the ultrasonic lengths (UL1 and UL2) is about three times the actual physical elongation of the fastener.

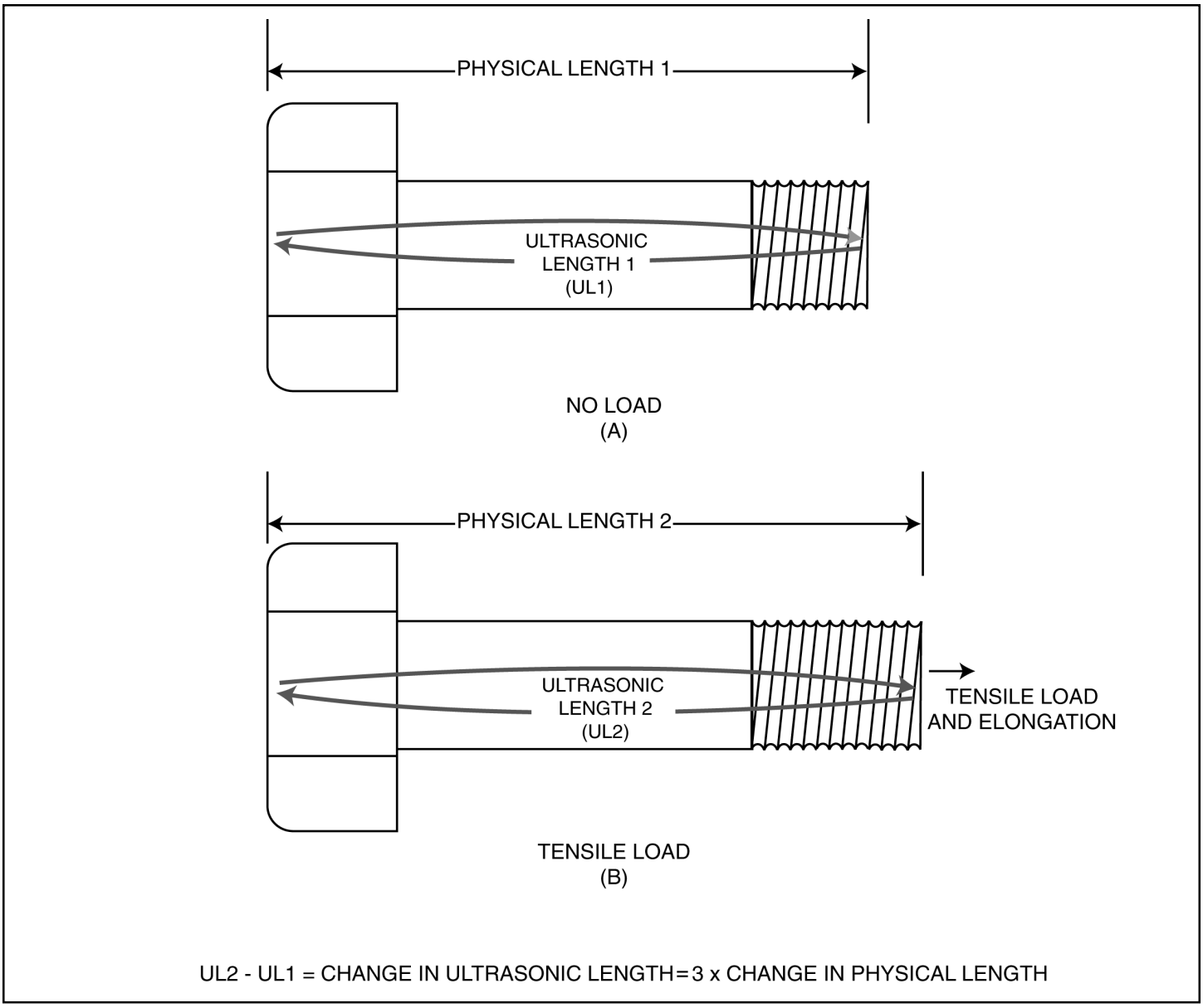

FIGURE 1-5—Applied tensile stress affects the ultrasonic (measured) length of a fastener in two ways. First, it stretches the fastener, thus increasing the actual length. Second, tensile stress reduces the fastener's acoustic velocity, further increasing its ultrasonic length. In the BoltMike, the material constant K (stress factor) is used to compensate for the effect of tensile stress on acoustic velocity.

It is important to note that in order to change the acoustic velocity, stress must be applied in the same direction traveled by the ultrasonic shock wave. Thus shear and torsional stress have no effect on the acoustic velocity when measured along the fastener's length.

1.1.10 Temperature Coefficient (Cp)

The temperature of a fastener affects its physical length. As the temperature of a fastener increases, its physical length increases. In addition, as a fastener's temperature increases the amount of time it takes for sound to travel through the fastener also increases. In other words, when a fastener is subjected to increased temperature, its acoustic velocity decreases and, therefore, its ultrasonic length increases. In fact, temperature's affect on ultrasonic length is even greater than its affect on physical length. The thermal expansion of the fastener and the ultrasonic velocity change with temperature are two separate effects. However, for the purpose of the BoltMike they are compensated for with a single combined factor known as the *Temperature Coefficient (Cp)*.

The Bolt Mike relies on a temperature compensation system to normalize the measured time of flight (TOF) and thus correct for temperature-caused changes in its physical and ultrasonic length. The compensation system normalizes the TOF to the value expected at 72 degrees Fahrenheit (22 degrees C) before attempting to calculate the fastener's stress, load, and elongation. This compensation greatly improves accuracy when the temperature has changed during tightening.

1.1.11 Calibration-Group Correction Factors — Stress Ratio and Offset

The accuracy of the BoltMike's stress, load, and elongation calculations depends on many factors. Two major influences on the accuracy of these calculations are the material-property constants inputted and the fastener's geometric characteristics.

While the material-property constants (including elasticity, acoustic velocity, and stress factor) are considered to be standard values, actual material properties vary widely. This variation is even found among fasteners produced in the same manufacturer's lot. The BoltMike's accuracy depends partly on the difference between the fastener's actual material properties and those properties represented by the standard material constants. Similarly, variations in fastening systems' physical characteristics affect the accuracy of load and elongation calculations.

When BoltMike III users desire to calculate load, elongation, stress, or TOF (time of flight) values with a higher degree of accuracy, they generally choose to create calibration groups. During the process of creating a calibration group, the BoltMike uses inputted values of actual tensile load, as well as its own measured load data, to calculate two correction factors: Stress Ratio and Stress Offset. These correction factors are used to convert the BoltMike's raw stress value into a corrected stress, as shown in Chapter 8 of this guide.

The BoltMike uses one of two methods to determine these correction factors. The first method, called a regression correlation, uses a linear regression technique to determine the stress factor and offset. (Figure 1-6) The stress factor is actually the slope of a line that represents the relationship between actual and calculated load. The stress offset represents the Y intercept of the actual verses calculated load line. This value can be thought of as the level to which actual load can increase before the BoltMike can measure an observable load.

The second method used to determine correction factors is known as vector correlation. With this approach the BoltMike calculates only a stress ratio. The value of the stress offset is set to zero. (Figure 1-6)

When creating a calibration group, the user must decide which correction method to use. This decision should be based on the application. If accuracy over a wide range of loads (including low-level loads) is desirable, the vector correction is usually preferred. If the highest level of accuracy at a single target load is desired, the regression method is best.

Why are two methods required? Often the relationship between actual and measured stress is non-linear, especially at the low end of the curve (as shown in Figure 1-6). This can be caused by a skin effect. When a small amount of load is applied to a fastener, most of the stress is in the surface layers, not evenly distributed across the cross-section. Since the longitudinal wave travels predominantly down the center of the fastener, less of the actual stress is observed.

1.1.12 Fastener Geometry

Several geometrical characteristics of fasteners affect the ultrasonic measurement of load, stress, and elongation. While these characteristics are described in great detail in Chapter 6 and the Appendix, Figure 1-7 briefly illustrates them.

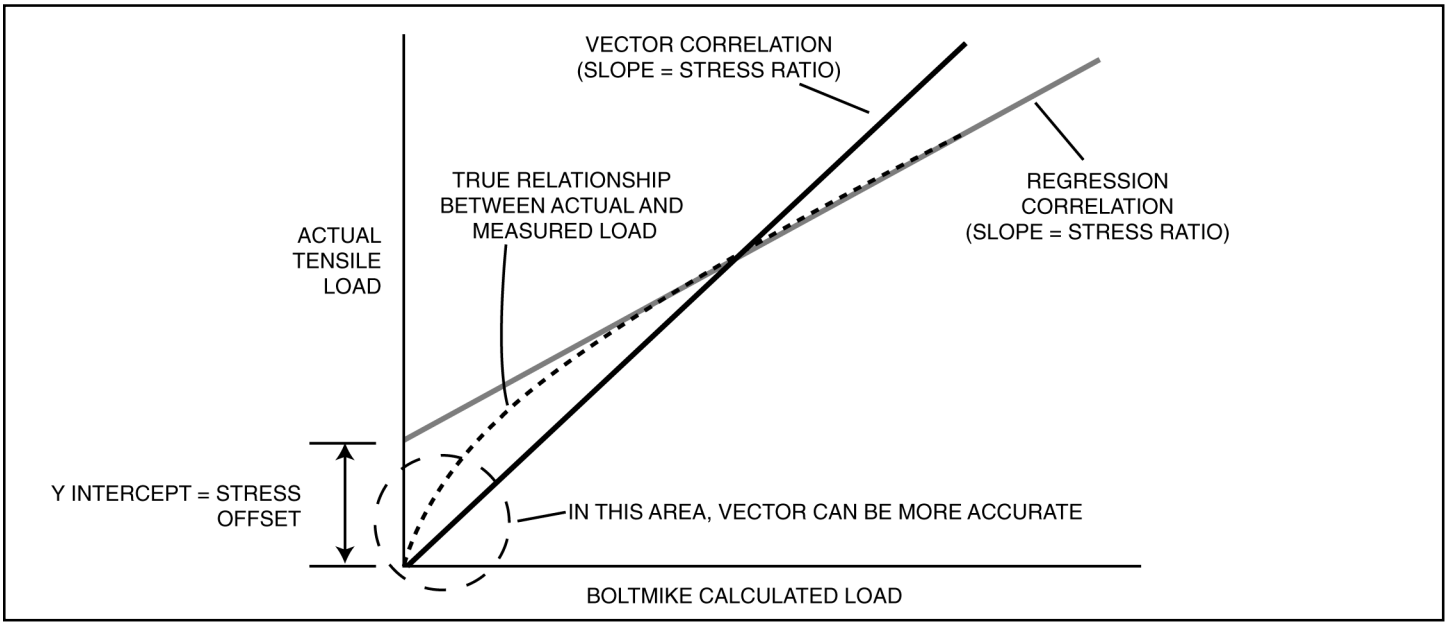

FIGURE 1-6—When the Calibration Group feature is used, known and measured loads for a group of fasteners are entered into the BoltMike. The correlation method chosen (vector or regression) determines if a stress ratio or a stress ratio and offset correction factor are then calculated.

As you'll learn in Chapter 6, the quantities inputted for fastener geometry have varying effects on the accuracy of the BoltMike's calculations. In general:

- Cross-Sectional Area—Affects the calculation of LOAD
- Effective Length—Affects the calculation of ELONGATION, LOAD, & STRESS
- Approximate Total Length—Affects only the position of the triggering gates

1.2 Principles of BoltMike Operation

NOTE: This section offers a brief description of fastener elongation measurement using ultrasonics. For more details on ultrasonic inspection techniques in general, refer to *ULTRASONIC TESTING OF MATERIALS*, by Josef and Herbert Krautkramer, 3rd Edition 1983, (IBSN 0-318-21482-3, 324), published by the American Society of Nondestructive Testing.

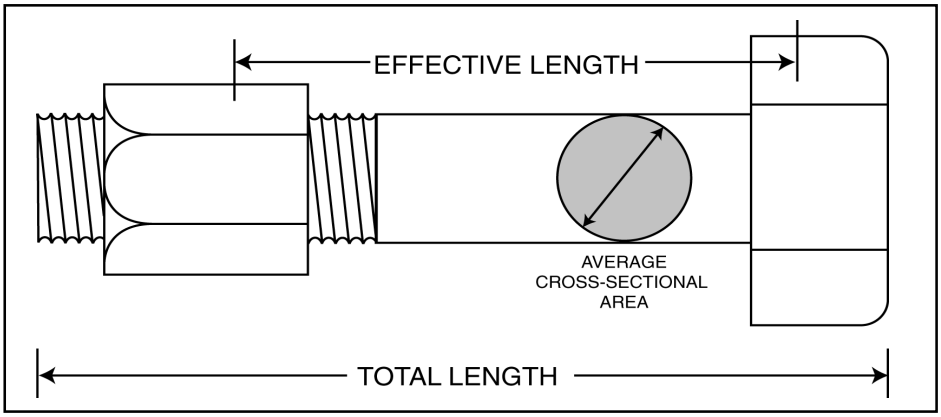

FIGURE 1-7—The geometrical characteristics of a fastener greatly affect the results obtained by ultrasonic inspection techniques. Included in these important characteristics are total length, effective length, and average cross-sectional area.

The BoltMike measures the time it takes for a sound wave to travel through a fastener. The sound wave, more specifically known as an ultrasonic shock wave or longitudinal wave, is created in the transducer. The wave is generated when a large electric pulse is sent to the transducer from the instrument. This pulse excites a piezoelectric element in the transducer. The wave's frequency varies with the thickness of the piezoelectric element. Frequencies most useful for measuring fasteners range from 1 to 20 MHz.

This range of ultrasound will not travel in air. Couplant, which is a dense liquid substance (usually glycerin or oil) must be used to provide a pathway for the ultrasound to travel from the transducer into the fastener.

When the ultrasonic wave encounters an abrupt change in material density, such as at the end of the fastener, most of the wave reflects. This reflection travels back the length of the fastener, through the layer of couplant, and back into the transducer. When the shock wave enters the piezoelectric element a small electrical signal is produced. The BoltMike detects this signal.

In I.P. mode (Initial Pulse mode is described in section 1.1.3), the BoltMike measures the elapsed time between the sound entering the material and the returned signal. This elapsed time is known as the wave's time of flight. Of course the time of flight actually represents the time taken by the wave to travel the length of the fastener two times. The TOF reported by the BoltMike equals half of this value.

In M.E. mode (Multi-Echo mode is described in section 1.1.3), the BoltMike measures the elapsed time between two consecutive returning signals. This elapsed time is equal to the wave's time of flight. As in I.P. mode this time of flight actually represents the time taken by the wave to travel the length of the fastener two times. The TOF reported by the BoltMike equals half of this value.

The BoltMike then determines the *ultrasonic length* by first using the temperature coefficient (Cp) to correct the TOF for any changes in temperature. The BoltMike then multiplies the corrected TOF by the fastener's acoustic velocity. Acoustic velocity is represented in the BoltMike with the variable V and is determined by the fastener's material type. The stress constant (K) and effective length are then used by the BoltMike logic to determine an uncorrected stress. As explained in Chapter 8, when the calibration-group feature is used, the stress ratio and offset are applied to this stress value to find a corrected stress.

Since the actual acoustic velocity is not truly a constant, and can vary significantly between fasteners of like material composition, the *change* in measured time of flight (recorded before and after each fastener is tensioned) must be used to accurately measure a fastener's stress, load, and elongation.

To determine the change in time of flight, the BoltMike first records a *reference length* by determining a normalized time of flight for a non-tensioned fastener. A normalized time of flight measurement of the same fastener, this time while tensioned, is then recorded. The two normalized TOF's (which have already been corrected for the effects of temperature) are then used with the effective length, stress factor (K), and acoustic velocity (V) to determine the uncorrected stress.

- The uncorrected stress is then corrected using the stress offset and stress ratio (these values are produced using a Cal group)
- Elongation is calculated using the corrected stress, effective length, and the modulus of elasticity.
- Load is also determined using the corrected stress and cross-sectional area.

1.3 Practical Limitations Of Ultrasonic Measurement

Included in the list of fastening-system types that are quite successfully inspected using ultrasonic techniques are those where equal distribution of load is critical, such as pipe flanges and head bolts where gaskets must be compressed evenly for optimum performance.

Not all threaded fastening systems are suitable for measurement by ultrasonic methods, and some systems are better suited to either multi-echo or initial pulse measurements. An understanding of ultrasonic inspection's practical limitations will reduce frustration and erroneous results.

1.3.1 Material Compatible with Ultrasonic Inspection

Most metals are excellent conductors of ultrasound. However, certain cast irons and many plastics absorb ultrasound and cannot be measured with the BoltMike.

1.3.2 Significant Fastener Stretch

Since ultrasonic techniques measure a fastener's change in length, a significant amount of stretch is required to produce accurate measurements. Accuracy is a significant problem in applications where the effective length of a fastener is very short, such as a screw holding a piece of sheet metal. These applications may be poorly suited to ultrasonic measurement because the tensile load (and therefore tensile stress) is applied over a very short effective length of the fastener. Because

the stressed length is so small, little or no measurable elongation of the fastener occurs.

In the same way, it is difficult to measure the effects of very low loads. Negligible elongation occurs when tensile stress levels are less than about 10% of the material's ultimate tensile stress. The small errors in measurement introduced by removing and replacing the transducer (as described in section 2.2) become very significant when trying to measure such a small amount of elongation.

1.3.3 Fastener End-Surface Configuration

The ends of bolt heads and threaded sections (bolts or studs) must be prepared before the fastener is fit for ultrasonic inspection. The fastener end that will be mated with a transducer must be machined to a very flat, smooth surface to allow for proper coupling of the transducer. The ideal finish for the transducer coupling point is between 32 to 63 micro inch CLA (0.8 to 1.6 micro meter Ra). Refer to section 2.1 to learn more about the requirements of fastener end-surface preparation.

Similarly, the surface at the opposite end of the fastener (known as the *reflective surface*) must be parallel to the surface that supports the transducer. This parallelism allows the reflective surface to reflect the ultrasound back to the transducer. While the finish of the reflective surface is not as critical, very rough or uneven finish can produce errors. Problems with surfaces are indicated by poor signal quality on the waveform display.

1.3.4 The Limitations of I.P. and M.E. Measurement Modes

Because M.E. measurement mode determines the elapsed time between two consecutively returning echoes, it eliminates some inconsistencies introduced in I.P. mode such as variation of couplant thickness and probe/instrument zeroing.

However, because M.E. mode relies on the second returning echo, and the quality of ultrasonic signals diminishes substantially with each returning echo, there are certain conditions under which the subsequent returning echoes will be distorted beyond acceptable limits and M.E. mode will not be effective. For instance, ultrasonic interference resulting from echoes off of the fastener's sidewalls increases the level of distortion present when the second returning echo is received. To some extent the sidewall distortion effect can be compensated for with the use of a larger diameter transducer. Similarly, the effects of frequency dispersion, attenuation, and sidewall distortion can also be compensated for by using a lower frequency transducer. In general lower transducer frequencies produce greater-amplitude returning echoes. Ultimately, however, some small-diameter, longer-length fastener measurements must be conducted in I.P. mode.

THIS PAGE WAS INTENTIONALLY LEFT BLANK.

Chapter 2: Fastener Preparation

Prior to measuring a fastener, it must be properly prepared for ultrasonic inspection. The fastener ends must be machined to be parallel and the end that will be mated with a transducer must be machined to a controlled, smooth surface finish. Further, to allow for proper coupling of the transducer and fastener, a suitable couplant must be applied. Finally, consistent placement of the transducer on the bolt head or stud end improves the instrument's accuracy and repeatability.

NOTE: Most fastener materials are excellent conductors of ultrasound. However, certain cast irons and many plastics absorb ultrasound and cannot be measured with the BoltMike.

2.1 Fastener End-Surface Machining

The ends of bolt heads and threaded sections (bolts or studs) must be prepared before the fastener is suitable for ultrasonic inspection. The fastener end that will be mated with a transducer must be perpendicular to the fastener's centerline and machined to a very flat, smooth surface to allow for proper coupling of the transducer. The ideal finish for the transducer coupling point is between 32 to 63 min. CLA (0.8 to 1.6 mm Ra). Inadequate surface finishes are indicated by poor signal quality on the A-scan display.

The reflective surface at the opposite end of the fastener must be parallel to the surface that mates with the transducer. As shown in Figure 2-1, this parallelism allows for identical sound-path distance regardless of the transducer's position. The degree to which these two surfaces are machined parallel determines the upper limit of an ultrasonic inspection system's accuracy.

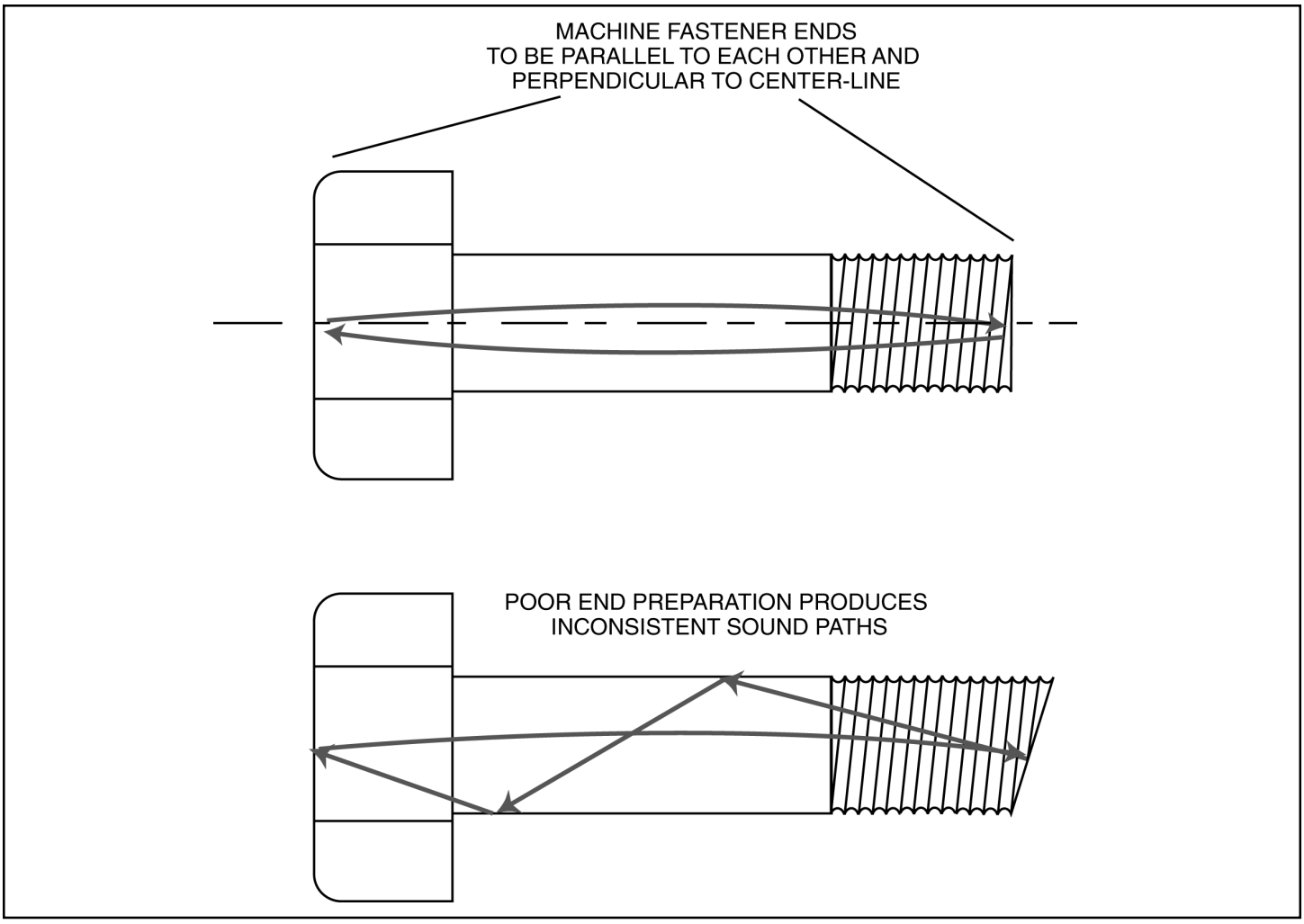
MACHINE FASTENER ENDS
TO BE PARALLEL TO EACH OTHER AND
PERPENDICULAR TO CENTER-LINE
POOR END PREPARATION PRODUCES
INCONSISTENT SOUND PATHS

FIGURE 2-1—Fastener ends must be uniform, parallel, and perpendicular to the fastener's centerline to ensure acceptable ultrasound transmission.

While the surface finish of the reflective surface is not as critical, very rough or uneven finish can produce errors. Use care when machining fastener ends. A common problem occurs when a small peak is left in the center of a fastener end after facing on a lathe. This small bump prevents the transducer from achieving proper contact and greatly reduces the signal amplitude.

NOTE: The use of Multi-Echo measurement mode reduces some types of variation and measurement inaccuracies, especially those that are due to couplant thickness and instrument/probe zeroing. However, errors introduced by inconsistent transducer placement or surface preparation techniques are not eliminated with the use of M.E. mode.

2.2 Methods Of Transducer Placement

Unless fastener ends and transducer surfaces are perfectly parallel, as discussed in section 2.1 of this manual, the reflected ultrasonic signal will vary with changes in the transducer's orientation, with respect to the fastener. This condition is illustrated in Figure 2-2. Optimal repeatability and accuracy are achieved by leaving the transducer attached to the fastener, in exactly the same location and angular orientation, throughout the tensioning process. As this ideal approach is often not possible or practical, the next best practice is to consistently return the transducer to the same location and angular orientation, with respect to the fastener. This practice improves the chances that the path followed by the shock wave when the reference length was measured is identical (or close to identical) to the path followed after the fastening system is tightened.

2.2.1 Practical Methods

Several practical methods are used to ensure consistent transducer placement. The most common method utilizes a magnetic transducer, which is placed in the center of the bolt's head. When inspecting bolts with diameters above one inch, refer to Figure 2-3 and follow these steps:

Step 1: First measure the reference (non-tensioned) length by coupling the transducer to the fastener end and adjusting its orientation, while observing the A-scan display. Position the transducer in the center of the fastener end and identify the angular transducer position that returns the A-scan waveform of greatest amplitude. At this point consider the accuracy of the selected measurement mode. M.E. mode can increase repeatability and improve accuracy if the subsequent returning echoes are free enough of distortion to be measured properly.

Step 2: Mark the transducer location and angular orientation on the fastener end.

Step 3: Continue with the fastener tightening procedure. If possible, the transducer should remain connected to the fastener end in exactly the same position and orientation. If this is not possible, proceed to step 4.

Step 4: Before proceeding, reconfirm that the position marked on the fastener end remains the location that returns the greatest-amplitude waveform and the shortest length and/or lowest load or stress reading. This step is important because in some cases, as the fastener is tensioned, a small amount of bending occurs. When bending occurs, the angular orientation that returns the

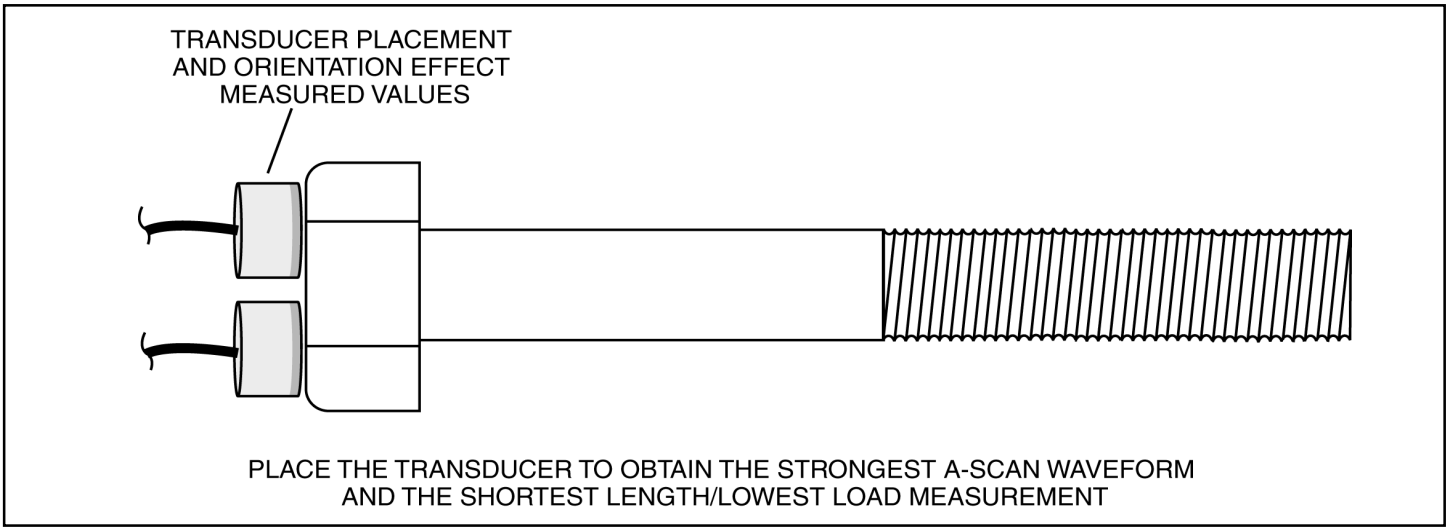
TRANSDUCER PLACEMENT
AND ORIENTATION EFFECT
MEASURED VALUES
PLACE THE TRANSDUCER TO OBTAIN THE STRONGEST A-SCAN WAVEFORM
AND THE SHORTEST LENGTH/LOWEST LOAD MEASUREMENT

FIGURE 2-2—Changing the transducer's position with respect to the fastener's end can change the shape and/or amplitude of the returned waveform. This effect is especially significant when inspecting long or large-diameter fasteners.

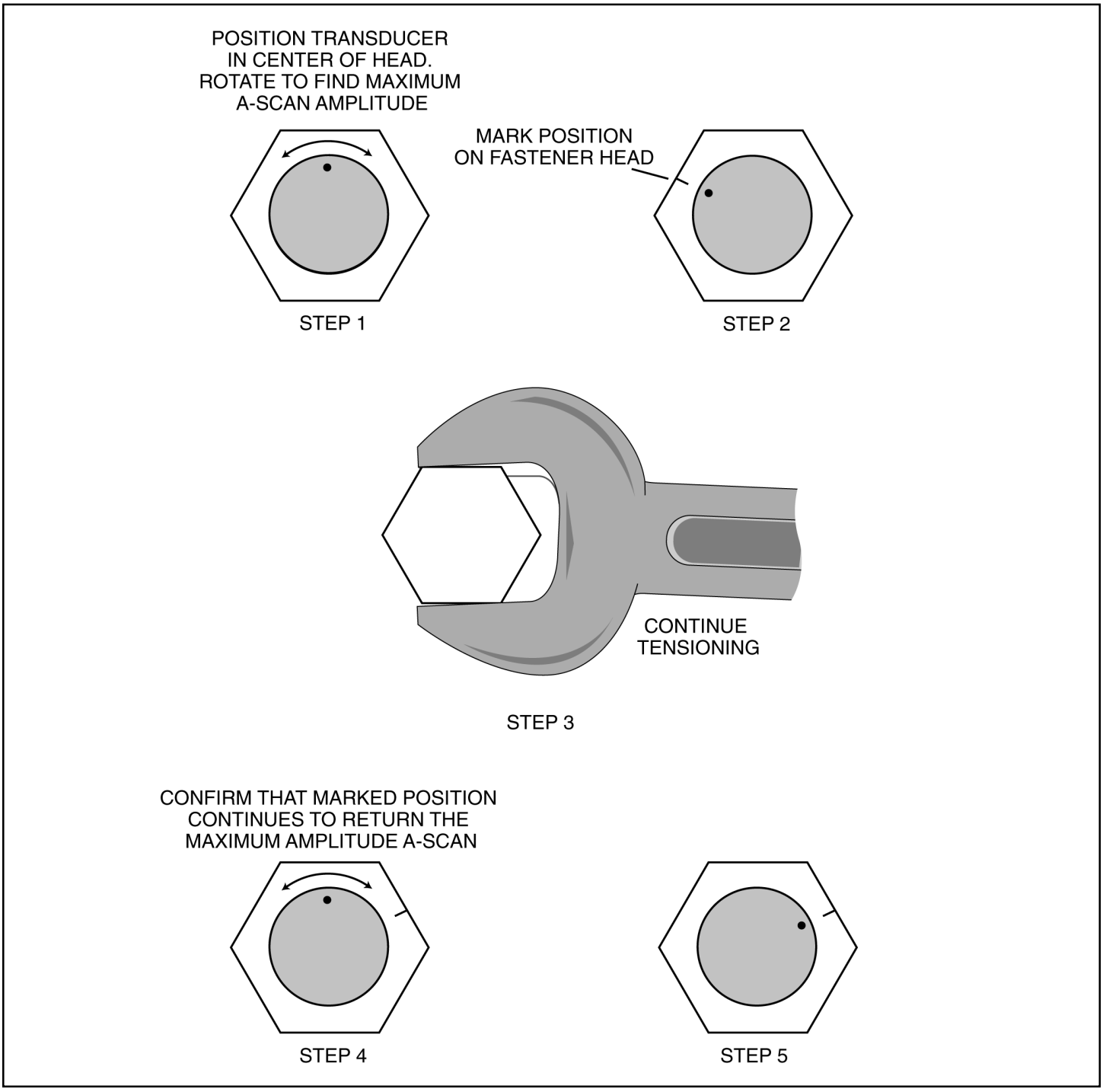

FIGURE 2-3—A consistent approach to transducer placement ensures accurate results.

maximum-amplitude waveform may change. If the maximum-response location has changed, adjust the position of the transducer to the new location on the bolt head. This assures the optimum sound path is being used, both before and after tightening.

Step 5: Position the transducer in the marked location (or at the newly identified maximum-amplitude location) to continue recording tensioned readings.

2.2.2 Fixtures for Non-Magnetic Fasteners

When fasteners are made of non-magnetic materials, fixtures are sometimes used to hold the transducer in place. Note that the fit between the transducer and the head of the bolt is extremely critical, and some provision must be made in the fixture to allow the transducer to "float" while finding the position where contact is at its best.

NOTE: Ultrasonic inspection techniques evaluate the change in length of a fastener. Fastener elongation occurs when a significant portion of the fastener (known as the effective length) is exposed to tensile loading. However, ultrasonic techniques are not effective when only a small percentage of the fastener's length experiences tensile loading (such as a screw holding a piece of sheet metal) or where load levels are below 10% of ultimate tensile stress.

Chapter 3: Transducer Selection

A wide variety of ultrasonic transducers are available. Suitability for a specific application is determined based on the transducer's center frequency, diameter, and damping. However, because there is often a broad range of applications for which transducers are suitable, and these ranges often overlap, it can be difficult to pick the "best" transducer for a specific job.

NOTE: It is a generally accepted practice that the same style and model probe be used when taking non-tensioned (L-Ref) and tensioned-fastener measurements of a fastener group. Further, it is preferable that the same probe be used to make tensioned and non-tensioned measurements of a fastener group.

3.1 General Acceptability

There is no single rule of thumb to follow when selecting a transducer for a specific application. For some fastening systems, many different types of transducers will measure with acceptable results. In the case of a hard-to-inspect fastener, transducer selection becomes more critical. The best way to evaluate an application is to use the Bolt Mike's waveform display and an assortment of transducers. Try making readings on a fastener that's similar or identical to the ones you'll be inspecting. Use several different transducers and observe the waveform display and the stability of the reading produced with each transducer. While you're using a transducer, observe the effects of removing and replacing it. Select the transducer that provides a large-amplitude signal and stable, repeatable readings.

3.2 Transducer Frequency

A transducer's frequency rating refers to the resonant frequency of the piezoelectric crystal. This is determined by the thickness of the crystal material. A thin crystal has a higher resonant frequency than a thick crystal. The BoltMike will work with transducers in the 1 to 15 MHz (megahertz) range.

The frequency of the transducer affects the transmission of ultrasound in two different ways, beamwidth and absorption. The *beamwidth* (also referred to as *directivity*) identifies how dispersed the shock wave becomes as it travels over a specific distance. Beamwidth decreases (that is, the wave becomes more tightly focused) as transducer frequency increases. This means that a 10 MHz transducer has a tighter beam (with a lower beamwidth) than a 5 MHz version of the same transducer. A tightly focused beam is desirable since it allows more energy to reach the end of the fastener, making the noise that reflects off the thread and shank areas less of an issue.

However, as frequency increases, the absorption of the ultrasound by the material also increases. Absorption refers to the material's ability to absorb (rather than reflect) ultrasonic sound energy. It interferes with the shockwave, reducing the received signal's resolution. Lower-frequency ultrasound travels around small flaws or air bubbles in the fastener's without significant interference to the shock wave. Absorption is an especially significant problem when inspecting more granular material such as is found in castings.

In conclusion, lower transducer frequencies are better suited as fastener lengths increase.

3.3 Transducer Diameter

A transducer's rated diameter actually refers to the diameter of its crystal. A transducer's diameter affects the efficiently with which it transmits sound as well as the beamwidth of the transmitted ultrasound. Remember, beamwidth identifies how dispersed the shock wave becomes as it travels over a specific distance. Beamwidth decreases (that is, the wave becomes more tightly focused) and transmitting efficiency increases as the diameter of the transducer's crystal increases. Again, a tightly focused beam is desirable since it allows more energy to reach the end of the fastener, making the noise that reflects off the thread and shank areas less of an issue.

It's generally preferable to select the largest-diameter transducer available that will still fit on the fastener to be measured. Note that external diameter of a transducer equipped with a built-in magnet is much larger than the piezoelectric crystal size. For example, a 1/4 inch 5 MHz non-magnetic transducer has a case with a 3/8-inch outside diameter. However, when a transducer with the same 1/4-inch crystal is mounted in a magnetic housing, the transducer's outside diameter is 3/4 inch.

Purpose of Instrument and Transducer Zeroing

The BoltMike's zeroing procedure occurs whenever the user presses the Inst Zero key and follows the steps as prompted. The procedure compensates for the actual delay that occurs while the transmitted pulse travels through the instrument's circuitry, the probe cable, and the probe's head and contact surface. Variations in different probes and cables, as well as changes in the trans-

ducer cable length, affect the necessary amount of time-delay compensation.

Repeat the transducer calibration whenever changing transducers or cables. As the probe's contact surface wears with use, the instrument should be periodically re-zeroed to compensate for any change in time delay.

NOTE: When operating in multi-echo measurement mode, the transducer and instrument zero do not affect the instrument's accuracy.

Chapter 4: Temperature Compensation

The temperature of a fastener affects its physical length. As the temperature of a fastener increases, its physical length increases. In addition, as a fastener's temperature increases the amount of time it takes for sound to travel through the fastener also increases. In other words, when a fastener is subjected to increased temperature, its acoustic velocity decreases and, therefore, its ultrasonic length increases. In fact, temperature's effect on ultrasonic length is even greater than its effect on physical length. The thermal expansion of the fastener and the ultrasonic velocity change with changing temperature are two separate effects. However, in the BoltMike's logic they are compensated for with a single combined factor known as the *Temperature Coefficient (Cp)*.

The BoltMike relies on its temperature compensation system to normalize the time of flight of a fastener and thus correct for temperature-caused changes in its physical and ultrasonic length. The compensation system normalizes the TOF to the value expected at 22.22 degrees C (72 degrees F) before attempting to calculate the change in the fastener's ultrasonic length. This compensation greatly improves accuracy when the temperature has changed during the time period between recording a reference length and a tensioned length.

4.1 Measuring Fastener Temperature

In some applications, significant differences in temperature exist from one portion of the fastener to another. Compensating for these temperature gradients is extremely difficult. Instead, the fastener's average temperature is used for temperature compensation. While the BoltMike allows manual input of temperature, it is preferable to input fastener temperature using the temperature probe.

The BoltMike's temperature sensor provides a convenient way to input fastener temperature. Because it magnetically couples to the metal of the fastener joint, it provides a very accurate temperature reading.

Typically, the temperature sensor is attached to the superstructure or frame that is being fastened, not each individual bolt. The probe is then left in place while the lengths of all fasteners in the area are ultrasonically measured.

NOTE: In most cases, air temperature has very little effect on fastener temperature and should not be entered as the temperature of the fastener. For optimum accuracy, use the temperature sensor and automatic temperature compensation.

NOTE: The range of the BoltMike temperature sensor is -55 degrees to 150 degrees C (-67 to 302 degrees F). Use of the sensor outside of these ranges will damage the sensor.

NOTE: Large accuracy problems can occur from handling the temperature sensor. Body heat conducted into the housing of the sensor will greatly increase the temperature reading. After holding the sensor in a bare hand, allow approximately ten to fifteen minutes for the temperature probe to stabilize. If while fastener measurement is underway a temperature sensor must be moved, handle it only while wearing a thick glove. Alternatively, you may carefully remove the temperature sensor by pulling on and handling only its cable.

4.2 Limits of Accurate Temperature Measurement

Errors in temperature compensation can have several causes including:

- Manual input of air (rather than) fasten temperature
- Contact between the operator's hand and the temperature sensor
- Variation of the material's temperature coefficient
- Materials' non-linear response to changes in temperature

The last two of these sources of error should be further explained. If a sample of physically identical bolts is tested for temperature coefficient, some bolt-to-bolt variation will be found. The amount of variation will depend on the type of material, and the uniformity with which the fasteners were manufactured. One way to compensate for this variation is to determine the range of actual temperature coefficients in the sample then decide of the difference between the actual and average values is too significant. Alternatively, a temperature calibration can be preformed for each fastener.

A materials actual response to changes in temperature (as represented in the BoltMike by the temperature coefficient) is not necessarily linear over a large range of temperatures. Although the thermal expansion of a fastener, when plotted against change in temperature, is very nearly linear, non-linearity is present in all materials. When trying to compensate for a large variation in temperature (in the range of fifty degrees Centigrade or

more), the nonlinear thermal reaction becomes a factor and significant errors may occur. When temperature variations are relatively large and increased accuracy is desired, the temperature coefficient may be adjusted to the specific temperature range.

4.3 Adjusting the Temperature Coefficient

If measurements are to be made over a large temperature range (50 degrees C or greater), the best results will be obtained by adjusting the temperature coefficient to the particular bolt and the specific temperature range.

Select at least two temperature levels that fall within the temperature range anticipated during the actual ultrasonic measurement. For example, the extremes of the temperature range may be 20 degrees C (representative of the shop temperature when the fasteners' reference length is recorded) and 70 degrees C (the temperature of the structure to which the bolt will be connected). In this case you might wish to examine the fastener at 20, 40, 50 and 70 degrees C.

Proper temperature calibration requires a means of controlling the bolt temperature such as a temperature oven. Place the bolt to be measured in the oven (set to the *lower* of your two target temperatures) with a transducer and temperature sensor attached. It is not necessary to load the bolt to determine the temperature coefficient.

In preparation for temperature calibration, create a group containing enough fasteners to store one L-REF for each of the fasteners you wish to sample. Measurements made (as described below) will only be stored as L-REFs. Create a custom material type (with the correct acoustic velocity) then assign it, along with a temperature coefficient of 0 (zero) to the group.

Allow plenty of time for the bolt in the oven to reach the target temperature. One way to tell when the internal temperature of the fastener has stabilized is to watch the L-REF change on the BoltMike. When the L-REF has been stable for two minutes, the temperature in the fastener is constant. This occurs because the displayed L-REF is temperature compensated. Record the fastener's measured length and the probe's temperature reading. Identify these as L1 and T1.

Change the oven setting to the higher temperature, monitor the bolt length until it again stabilizes, and repeat the process described above. Identify the second measured length and temperature as L2 and T2.

You should now have recorded at least two ultrasonic length measurements at different temperatures. Two measurement points will allow you to calculate a value of Cp. These calculated values of Cp must be averaged over a temperature range to find the best value of Cp in the temperature range of your test. In the following formula, L1 and T1 are the reference length and temperature for data point 1, and L2 and T2 the reference length and temperature for data point 2.

$$Cp = \left(\frac{1}{T2 - T1}\right)\left(\frac{L2}{L1} - 1\right)$$

If readings are taken across a temperature range (for example, at four temperatures) you can calculate a Cp for T1 and T2, as well as a Cp for T3 and T4. Then, average the two calculated values for Cp to produce an average Cp over the temperature range.

Chapter 5: Selecting Phase

When recording a reference (non-tensioned) fastener length, the operator must first select a measurement phase. This setting determines if the triggering gate is positioned above or below the A-scan zero level and, therefore, if the gate detects positive or negative heading portion of the signal.

Once the measurement phase is selected, and an L-Ref is recorded, the phase may not be changed again for that fastener. Therefore, it is critical that the user first examine the A-scan shape in non-tensioned and tensioned loading conditions. As shown in Figure 5-1, there are often low-amplitude half-cycle features visible on the A-scan. These echoes should not be used to trigger the gate as they are not valid representations of a returning echo. However, the first valid echo available should be used to trigger the gate (especially in Multi-Echo mode) as later echoes may be substantially affected by sidewall distortion. Sidewall distortion results from sound energy reflecting off of the fastener's sidewalls, into the primary sound path, and back towards the transducer.

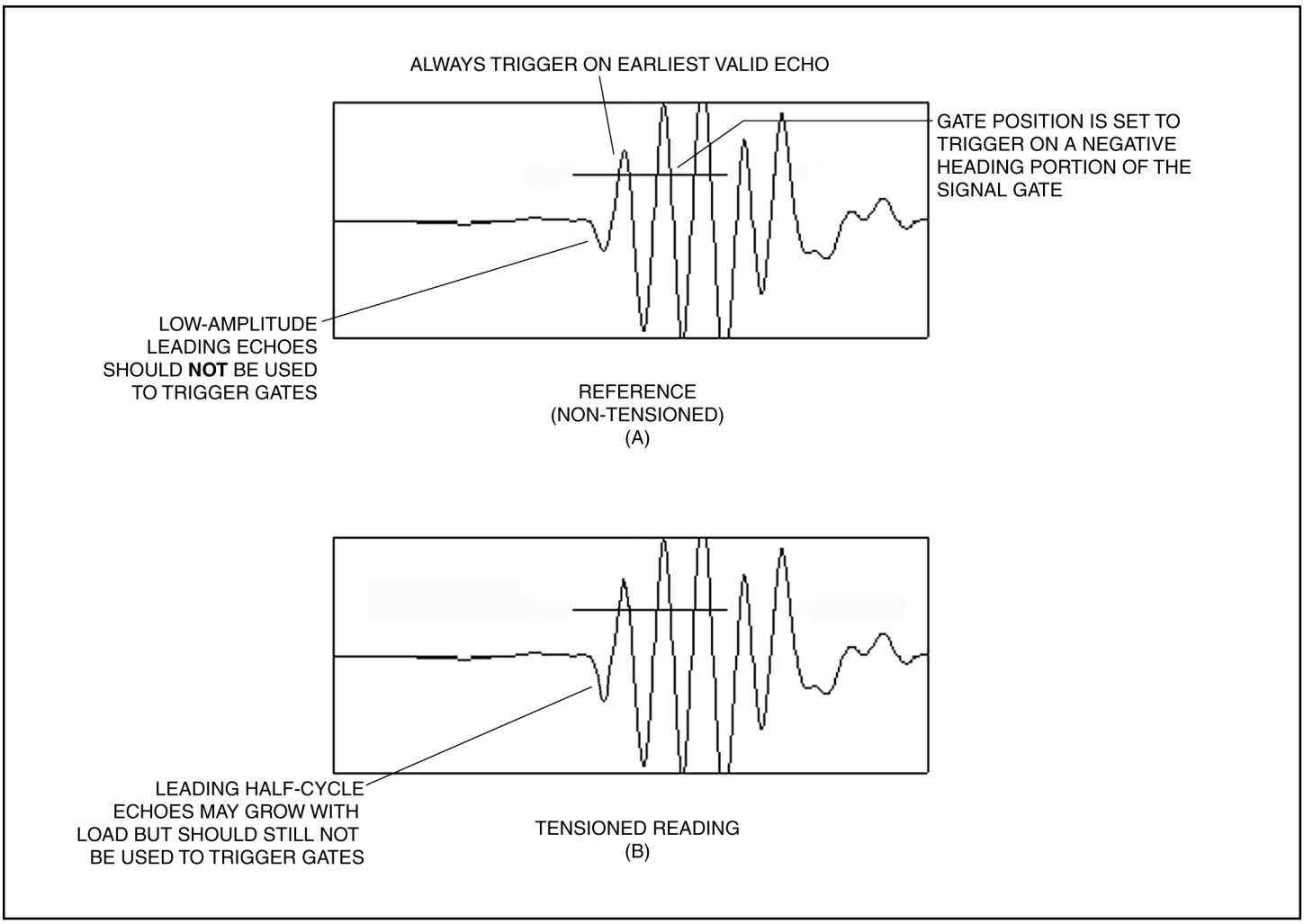
ALWAYS TRIGGER ON EARLIEST VALID ECHO
GATE POSITION IS SET TO TRIGGER ON A NEGATIVE HEADING PORTION OF THE SIGNAL GATE
LOW-AMPLITUDE LEADING ECHOES SHOULD **NOT** BE USED TO TRIGGER GATES
REFERENCE (NON-TENSIONED) (A)
LEADING HALF-CYCLE ECHOES MAY GROW WITH LOAD BUT SHOULD STILL NOT BE USED TO TRIGGER GATES
TENSIONED READING (B)

FIGURE 5-1—Select the PHASE to trigger off of the first valid echo available in both the non-tensioned and tensioned condition. Note that invalid echoes before the first valid echo and distortion-affected later echoes should not be used to trigger gates.

THIS PAGE WAS INTENTIONALLY LEFT BLANK.

Chapter 6: Fastener Geometry

As explained throughout Chapter 1 of this guide, many of the calculations made by the BoltMike rely directly on user-input fastener dimensions. A fastener's material type, nominal length, average diameter, and effective length (also known as working or grip length) must be input in order for the BoltMike to perform all calculations.

While material types and the constants that define their properties are described in Chapter 7, this chapter deals with the geometric properties that define a fastener's shape. Some of a fastener's geometric properties have little effect on certain BoltMike calculations, while others have a significant effect. It is important to understand how each geometric property affects the BoltMike's output.

6.1 Approximate Length

In the BoltMike, the approximate length is the total length of the fastener. In terms of ultrasonics, this is the distance from the ultrasonic transducer to the opposite (reflecting) end of the fastener. The approximate length is used to determine the distance at which the BoltMike's receiver is enabled.

While the accuracy of the quantity entered for total fastener length does not directly affect the accuracy of the BoltMike readings, entering a significantly incorrect value for total length may result in unstable or no readings at all. If the value entered for approximate length is too large, the first echo that returns from the bolt will be ignored. If the value entered for approximate length is too short, the BoltMike will not detect the correct returning echo. These two cases are shown in Figure 6-1.

6.2 Determining Effective Length

When a fastening system is tensioned, the length of the fastener to which the tensile load is applied is known as its effective length. When considering a constant applied load, the amount of fastener elongation is directly proportional to a fastener's effective length. In other words, if two fastening systems are identical in all ways, including the tensile load on the fastener, except that the effective length of the first fastener is twice the effective length of the second, then the elongation of the first fastener will be twice the elongation of the second.

The effective length must be entered into the BoltMike in order to make any measurement other than the reference length. However, the accuracy of the value entered as the effective length has almost no influence on the accuracy of the elongation measurement. And then, the affect on elongation measurement is only noticeable at very high tensile loads, approaching the material's yield strength. Because the measurement of elongation is virtually independent of the effective length, tension loading is specified in terms of elongation in applications where the ability to accurately determine effective length is questionable.

However, the accuracy of the value entered for effective length has a direct influence on the accuracy of measured stress and load. If the value entered for effective length is ten percent less than the actual value, the error in load and stress measurements will be ten percent.

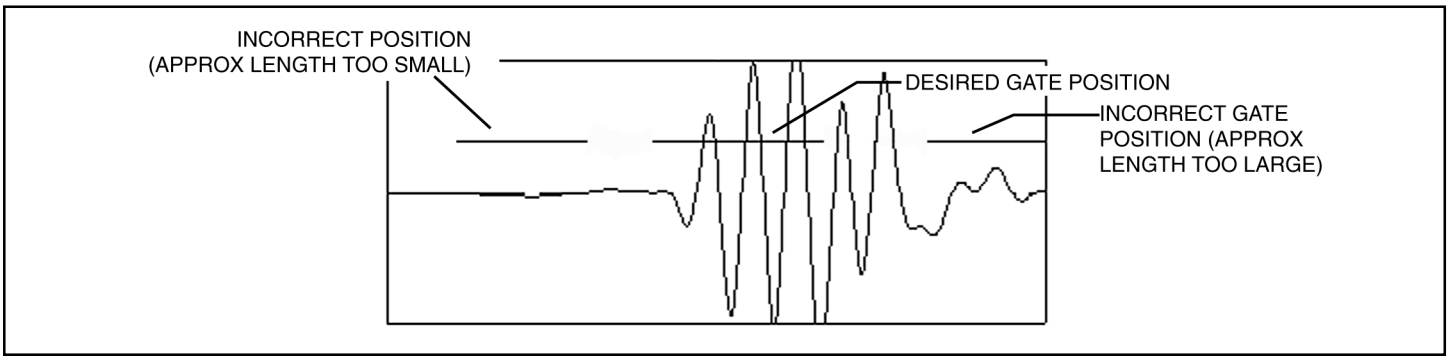

FIGURE 6-1—The value of approximate total length is used only to set the position of the gate(s) on the A-scan display screen.

The effective length is calculated differently depending on the fastener application. The directions for calculating the effective length in four different cases are outlined in Figures 6-2 through 6-5. Note that the resulting values for effective length are approximate and may vary due to certain other factors. For example, consider an application using a bolt in a blind hole. Suppose the material strength of the bolt is greater than the threaded hole. The weaker threads in the hole will flex more than the threads of the bolt, and the effective length will be longer than if the materials were of the same material.

For the best accuracy of load or stress readings, calibrate the BoltMike for the specific application. This will cancel errors due to effective length uncertainty. In this approach a calibration group is formed (using fasteners that are the same or similar to the ones being tested). The fasteners are inserted in a fixture that loads them at the same effective length with a known quantity of load.

Refer to Figures 6-2 through 6-5 to identify the fastening system closest to the one you are evaluating. Then follow the instructions in the applicable figure to calculate effective loading. The figures show:

- Stud fastening system (Figure 6-2)
- Through bolt fastening system (Figure 6-3)
- Bolt (screw) turned into a threaded hole (Figure 6-4)
- Stud turned into a threaded hole (Figure 6-5)

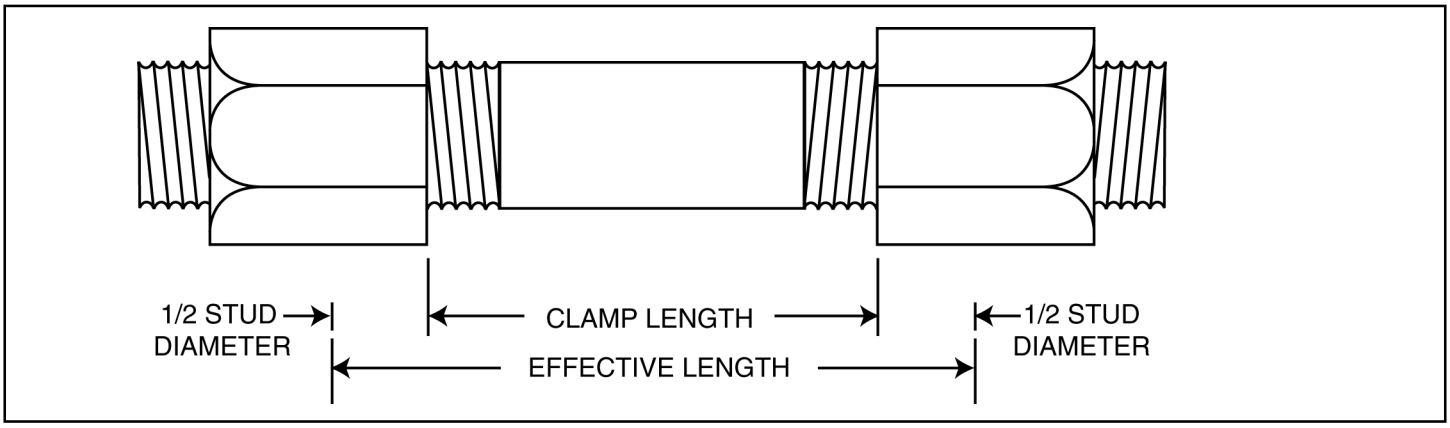

FIGURE 6-2—This is a typical stud configuration. The effective length of a stud with nuts on each end is found by adding the stud diameter to the clamp length.

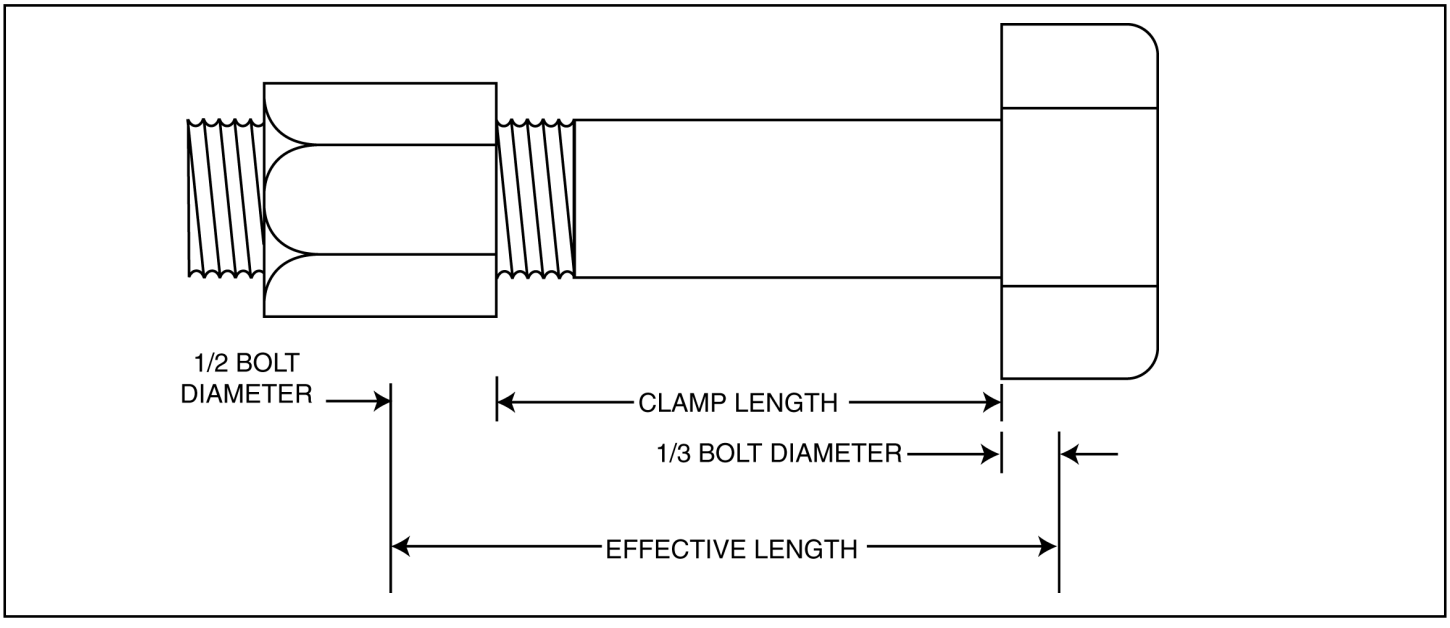

FIGURE 6-3—This is a typical through bolt configuration. The effective length of a bolt with a single nut is found by adding half the diameter to one-third the diameter (5/6 of the diameter total) to the clamp length.

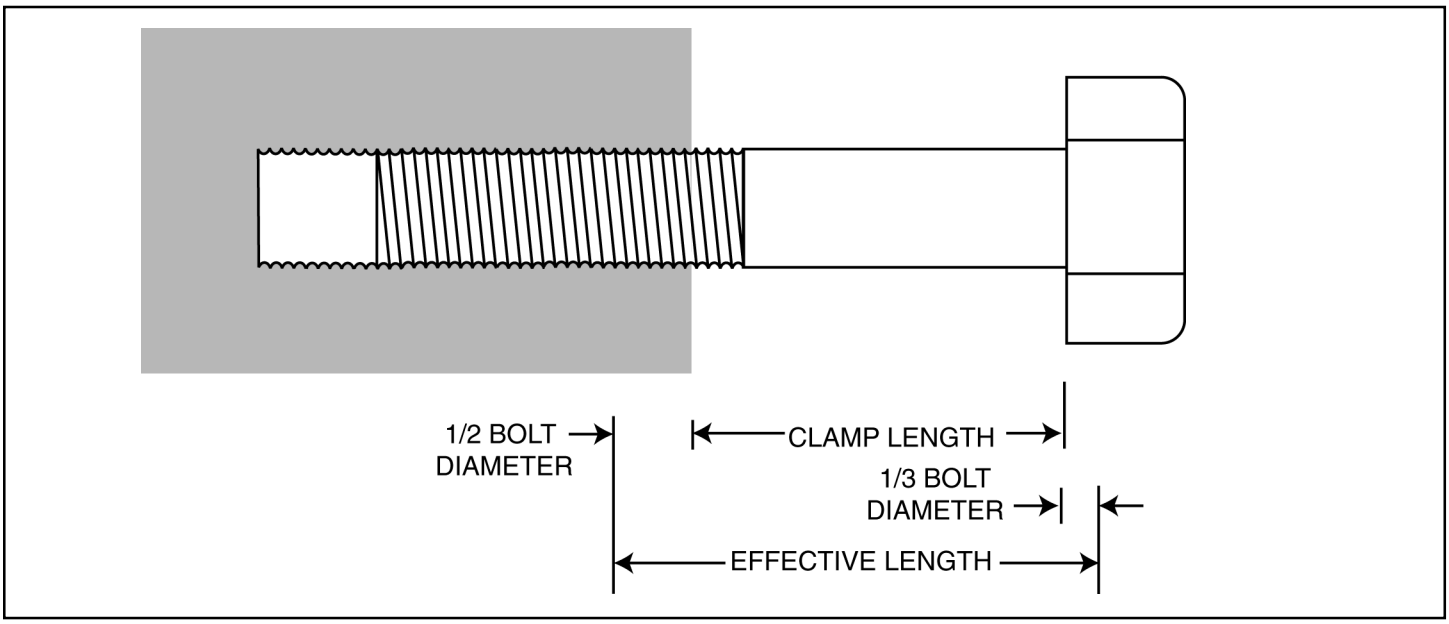

FIGURE 6-4—This is typical of a configuration with a bolt (screw) turned into a threaded hole. When a headed fastener is threaded into a metal block, such as an automotive head bolt, calculate the effective length by adding half the diameter to one third the diameter (5/6 of the diameter total), then adding this amount to the clamp length.

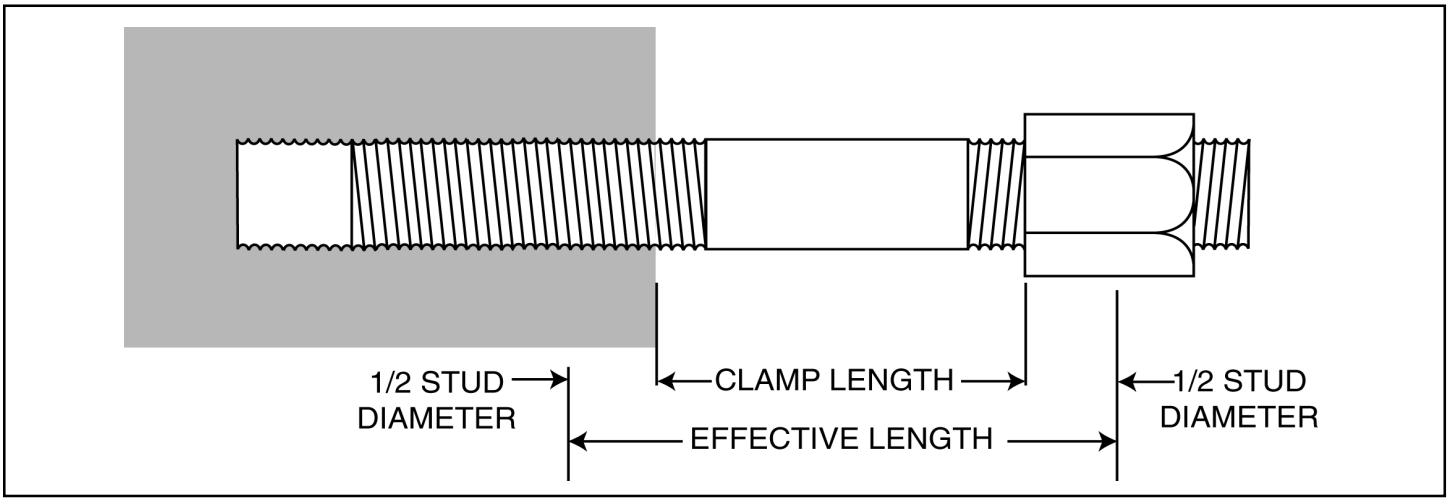

FIGURE 6-5—This is typical of a configuration with a stud turned into a threaded hole. When a stud is threaded into A blind hole and a nut is placed on the opposite end, find the effective length by adding the stud diameter to the clamp length.

6.3 Fastener Cross-Sectional Area

The cross-sectional area is the average area of that portion of a fastener that is subjected to tensile loading. In other words, it's an average cross-sectional area taken over only the fastener's effective length. The cross-sectional area in threaded portions of the fastener should be calculated based on the thread's minor diameter. The accuracy with which cross-sectional area is entered only affects the BoltMike load calculation. It has no effect on the stress or elongation measurement.

The accuracy of the value entered for cross-sectional area has a direct influence on the accuracy of measured load. If the value entered for cross-sectional area is ten percent less than the actual value, then the measured value of load will be ten percent lower than the actual value.

If a fastener's geometry is more complex, with varying values of cross-sectional area along its effective length, the various areas over the effective length may be averaged to arrive at an overall average cross-sectional area. In the case of a hollow fastener, the area of the hole must be subtracted from the overall average cross-sectional area to determine the actual cross sectional area. To calculate the average cross-sectional area of a fastener, multiply the length of each segment along the effective length of the fastener by the cross-sectional area of each specific segment. (Figure 6-6) Add all of the resulting values, and then divide the total by the sum of the lengths.

In the appendix of this manual, you will find tables of average cross-sectional areas for various types and sizes of common fastener.

For the best accuracy of load readings, calibrate the BoltMike for the specific application. This will cancel errors due to cross sectional area uncertainty. In this approach a calibration group is formed (using fasteners that are the same or similar to the ones being tested). The fasteners are inserted in a fixture that loads them at the same effective length with a known quantity of load.

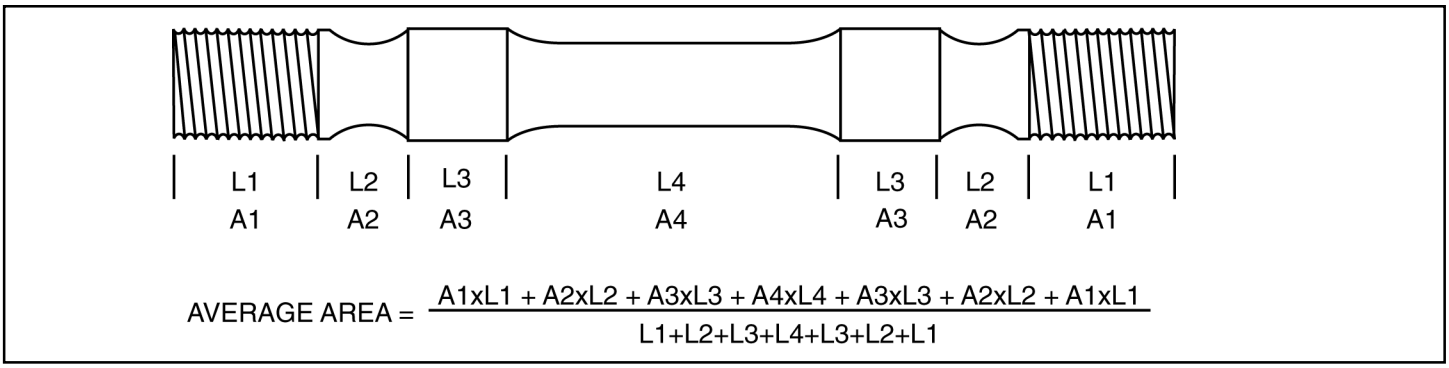

FIGURE 6-6—Follow this procedure to determine the average cross-sectional area over the effective length of an irregular fastener.

Chapter 7: Material Constants

As described in Chapter 1 of this guide, several constants are used by the BoltMike to represent the material properties of a specific fastener. You have the option of using constants already stored in the BoltMike for standard material types or defining constants for a custom material type.

7.1 Standard Material Constants

While constants are stored in the BoltMike for twelve standard material types, as shown in Table 7-1, any other material type and it's related constants may be entered using the CUSTOM material type feature.

Material constants used by the BoltMike include:

Vo—Acoustic Velocity (described in section 1.1 of this guide)

Eo—Modulus of Elasticity (described in section 1.1.8 of this guide)

Cp—Thermal Coefficient (described in sections 1.1.10 and 4.3 of this guide)

K—Stress Factor (described in section 1.1.9 of this guide)

Y—Yield Strength (described in section 1.1.8 of this guide)

The material constants listed in Table 7-1 are stored in the BoltMike for the twelve standard material types listed.

7.2 Custom Material Constants

StressTel offers laboratory material calibration at a nominal cost. This service is highly recommended for users of exotic material or in applications where highest accuracy is required.

7.3 Selecting a Material Constant

There are several ways to select a bolt material constant. The best way is to compare the published specifications for the material you wish to evaluate against those of the standard material types listed in Table 7-1. First identify the standard material type that's closest in properties to the non-standard material type you wish to test. Next, while creating a Group in the BoltMike, first select the standard material type that most closely resembles the properties of your non-standard material, and then press (F1) to enter the CUSTOM material mode. When

Table 7-1

Standard Material Types and Constants Stored in the BoltMike

Name	Material Type	Vo (m/s)	Cp (1/deg C)	Eo (MPa)	K (m/s/Pa)	Y (MPa)
B7	ASTM A193 B7	5964.7303	0.00007704	206206.8966	0.00000009062990	655.8621
B16	ASTM A193 B16	5957.3211	.00007704	206206.8966	0.00000009468245	655.8621
8.8	ISO 8.8	6047.9915	0.00007704	206206.8966	0.00000011457682	627.9593
9.8	ISO 9.8	5842.0000	0.00007704	206206.8966	0.00000013999740	720.6897
10.9	ISO 10.9	6047.2295	0.00007704	206206.8966	0.00000011162954	882.9428
11.9	ISO 11.9	5997.6995	0.00007704	206206.8966	0.00000010720853	991.0345
12.9	ISO 12.9	5739.8895	0.00007704	206206.8966	0.00000008989307	1058.9310
304SS	304 Stainless Steel	5725.9703	0.00010304	193103.4483	0.00000009210355	209.9862
316SS	316 Stainless Steel	5690.8192	0.00010304	193103.4483	0.00000008841941	209.9862
1020S	1020 Mild Steel	5964.7303	0.00007704	200000	0.00000008105113	295.1724
MONEL	MONEL	5697.9795	0.00014596	193103.4483	0.00000009210355	274.9821
A490	A490 Structural Steel	5928.6394	0.00007704	200000	0.00000008068271	896.5517

the CUSTOM material mode is activated, you edit the material name and any material property to match those of your non-standard material type.

Even if you are able to obtain published constants for a non-standard material type, it is best to perform some amount of testing to determine the accuracy of the resulting measurements.

Another way to determine the bolt type is to measure a group of bolts and use the built in calibration function to determine which material type gives the minimum error. In this approach a calibration group is formed (using fasteners that are the same or similar to the ones being tested). The fasteners are inserted in a fixture that loads them at the same effective length with a known quantity of load.

7.4 Material Variations

Many materials exhibit very uniform material constants. However, material constants in samples of some materials will vary widely.

A material's elastic modulus has a direct effect on that material's acoustic velocity (Vo) and stress factor (K). Hardening or heat treatment of the material or relaxation of the hardening will affect the accuracy of the standard values of these constants. In fact, the constants in some materials can vary dramatically as a result of work hardening of the material. Therefore, it is strongly suggested that a sample of the bolts be tested to confirm the accuracy of the material properties you've chosen under actual loading conditions.

Chapter 8: BoltMike Formulas

The BoltMike uses the following collection of formulas as a basis for all calculations and derived values. If using the formulas manually, be certain to convert all values to the units listed below, and to adhere to accepted rounding practices and number of significant digits. Finally, keep in mind that all BoltMike calculations are performed in metric units. When English units are displayed, the conversion from metric to English takes place after values are calculated.

Units

Temperature:	Degrees C
Thermal Coefficient (Cp):	1 / Degrees C
Time of Flight (TOF):	s (Seconds)
Acoustic Velocity (Vo):	m/s (Meters per sec.)
All values of length:	m (Meters)
Modulus of Elasticity (Eo):	Pa (Pascal)
Stress Factor (K):	m/s/Pa (meters per second per Pascal)
Yield Strength (Y):	Pa (Pascal)
Uncorrected Stress:	Pa (Pascal)
Corrected Stress:	Pa (Pascal)
Stress Offset:	Pa (Pascal)
Cross-Sectional Area:	m^2 (Square meters)
Load:	kN (KiloNewton)

NOTE: The units of measurement listed above are those units used in the following equations. These are not in all cases the same units that are displayed by the instrument, nor are they necessarily the same units as listed in tables throughout this guide.

Measured Time of Flight (TOF)

$$TOF_{measured} = \frac{\text{Sound Path Duration}}{2}$$

Reference Length (LREF)

$$LREF = TOF_{measured} * V$$

Temperature Normalization

$$TOF_{normal} = TOF_{measured} * [1 + (Cp * (Temp_{measured} - 22.22))]$$

Change in Ultrasonic Length

$$\text{Change in Ultrasonic Length} = (V * TOF_{normal\text{-}stressed}) - (V * TOF_{normal\text{-}reference})$$

Stress Calculation and Correction

$$Stress_{uncorrected} = \frac{V}{K} * \frac{(\text{Change in Ultrasonic Length})}{(\text{Change in Ultrasonic Length} + \text{Effective Length})}$$

$$Stress_{corrected} = Stress_{uncorrected} * \left(1 + \frac{\text{Stress Ratio}}{100}\right) + \text{Stress Offset}$$

Load

$$Load = Stress_{corrected} * \text{Cross-Sectional Area}$$

Elongation

$$\text{Elongation} = \frac{Stress_{corrected} * \text{Effective Length}}{Eo}$$

THIS PAGE WAS INTENTIONALLY LEFT BLANK.

Appendix: Tabular Data

NOTE: The tables contained in this appendix give the cross sectional stressed area for many standard sizes of bolt. The operator may choose to use these tables to determine the area of a fastener. IMPORTANT: These tables are provided for convenience only - StressTel does not assume liability for errors.

In this appendix you will find these tables:

- Material Constants – Units of measurement (English and Metric) for each of the BoltMike's constant or measured values
- Metric Standard Thread
- Metric Fine Thread
- Metric Standard Thread, Waist Bolts
- Metric Fine Thread, Waist Bolts
- Extra Fine Thread Series, UNEF and NEF
- Fine Thread Series, UNF and NF
- Coarse Thread Series ,UNC and NC
- 4 Thread Series, 4UN
- 6 Thread Series, 6UN
- 8 Thread Series, 8UN
- 12 Thread Series, 12UN
- 16 Thread Series, 16UN
- 20 Thread Series, 20UN
- 28 Thread Series, 28UN
- 32 Thread Series, 32UN

The BoltMike stores data in metric form. If a number is entered in English units, it is converted to metric for internal use, and then converted back to English to be displayed. The following table shows the displayed units of the BoltMike in both English and metric.

Material Constants		
ITEM	**ENGLISH**	**METRIC**
Vo(Velocity)	Inches per microsecond (in/µs)	Meters per Second (m/s)
Cp(Temp coef)	x per degree Fahrenheit (/ °)	x per degree Centigrade (/ °)
Eo(elast. mod)	Pounds per Square Inch (psi)	MegaPascals (MPa)
K(dV/force)	Inches per Second per Pounds per Square Inch (in/s/psi)	Meters per Second per Pascal (m/s/Pa)
Y (Yield)	Pounds per Square Inch (psi)	MegaPascals (MPa)
Geometry Factors		
L Approx	Inches (in)	Millimeters (mm)
L Effective	Inches (in)	Millimeters (mm)
Area	Square Inches (in^2)	Square Millimeters (mm^2)
Measured Quantities		
L-REF	Inches (in)	Millimeters (mm)
Elongation	Inches (in)	Millimeters (mm)
Stress	Pounds per Square Inch (psi)	MegaPascals (MPa)
Load	Pounds (lb)	KiloNewtons (KN)
Temperature	Degrees Fahrenheit (°)	Degrees Centigrade (°)

NOTE: The following tables give the cross sectional stressed area for many standard sizes of bolt. Use these tables to determine the area to enter into the bolt group. IMPORTANT: These tables are provided for convenience only - StressTel cannot assume liability for errors.

METRIC STANDARD THREAD		
Sizes mm	**Pitch mm**	**Tensile Stress Area Sq. mm**
M 4	0.7	8.78
M 5	0.8	14.2
M 6	1.0	20.1
M 7	1.0	28.9
M 8	1.25	36.6
M 10	1.5	58.0
M 12	1.75	84.3
M 14	2.0	115
M 16	2.0	157
M 18	2.5	193
M 20	2.5	245
M 22	2.5	303
M 24	3.0	353
M 27	3.0	459
M 30	3.5	561
M 33	3.5	694
M 36	4.0	817
M 39	4.0	976

METRIC FINE THREAD		
Sizes mm	**Pitch mm**	**Tensile Stress Area Sq. mm**
M 8	1.0	39.2
M 9	1.0	51
M 10	1.0	64.5
M 10	1.25	61.2
M 12	1.25	92.1
M 12	1.5	88.1
M 14	1.5	125
M 16	1.5	167
M 18	1.5	216
M 18	2.0	204
M 20	1.5	272
M 22	1.5	333
M 24	1.5	401
M 24	2.0	384
M 27	1.5	514
M 27	2.0	496
M 30	1.5	642
M 30	2.0	621
M 33	1.5	784
M 33	2.0	761
M 36	1.5	940
M 36	3.0	865
M 39	1.5	1110
M 39	3.0	1028

METRIC STANDARD THREAD WAIST BOLTS			
Sizes mm	**Pitch mm**	**Waist Diameter mm**	**Tensile Stress Area Sq. mm**
M 4	0.7	2.83	6.28
M 5	0.8	3.62	10.3
M 6	1.0	4.30	14.5
M 7	1.0	5.20	21.2
M 8	1.25	5.82	26.6
M 10	1.5	7.34	42.4
M 12	1.75	8.87	61.8
M 14	2.0	10.4	84.8
M 16	2.0	12.2	117
M 18	2.5	13.4	142
M 20	2.5	15.2	182
M 22	2.5	17.0	228
M 24	3.0	18.3	263
M 27	3.0	21.0	346
M 30	3.5	23.1	420
M 33	3.5	25.8	524
M 36	4.0	28.0	615
M 39	4.0	30.7	739

METRIC FINE THREAD WAIST BOLTS			
Sizes mm	**Pitch mm**	**Waist Diameter mm**	**Tensile Stress Area Sq. mm**
M 8	1.0	6.10	29.2
M 9	1.0	7.00	38.4
M 10	1.0	7.90	49.0
M 10	1.25	7.62	45.6
M 12	1.25	9.42	69.7
M 12	1.5	9.14	65.7
M 14	1.5	10.94	94.1
M 16	1.5	12.74	128
M 18	1.5	14.54	166
M 18	2.0	13.99	154
M 20	1.5	16.34	210
M 22	1.5	18.14	259
M 24	1.5	19.94	312
M 24	2.0	19.39	295
M 27	1.5	22.64	403
M 27	2.0	22.09	383
M 30	1.5	25.34	504
M 30	2.0	24.79	483
M 33	1.5	28.04	618
M 33	2.0	27.49	594
M 36	1.5	30.74	742
M 36	3.0	29.09	664
M 39	1.5	33.44	878
M 39	3.0	31.79	794

EXTRA FINE THREAD SERIES, UNEF AND NEF			
Sizes in.	**Basic Major Diameter in.**	**Threads per in.**	**Tensile Stress Area Sq. in.**
12(.216)	0.2160	32	0.0270
1/4	0.2500	32	0.0379
5/16	0.3125	32	0.0625
3/8	0.3750	32	0.0932
7/16	0.4375	28	0.1274
1/2	0.5000	28	0.170
9/16	0.5625	24	0.214
5/8	0.6250	24	0.268
11/16	0.6875	24	0.329
3/4	0.7500	20	0.386
13/16	0.8125	20	0.458
7/8	0.8750	20	0.536
15/16	0.9375	20	0.620
1	1.0000	20	0.711
1 1/16	1.0625	18	0.799
1 1/8	1.1250	18	1.901
1 3/16	1.1875	18	1.009
1 1/4	1.2500	18	1.123
1 5/16	1.3125	18	1.244
1 3/8	1.3750	18	1.370
1 7/16	1.4375	18	1.503
1 1/2	1.5000	18	1.64
1 9/16	1.5625	18	1.79
1 5/8	1.6250	18	1.94
1 11/16	1.6875	18	2.10

FINE THREAD SERIES, UNF AND NF			
Sizes in.	**Basic Major Diameter in.**	**Threads per in.**	**Tensile Stress Area Sq. in.**
0(.060)	0.0600	80	0.00180
1(.073)	0.0730	72	0.00278
2(.086)	0.0860	64	0.00394
3(.099)	0.990	56	0.00523
4(.112)	0.1120	48	0.00661
5(.125)	0.1250	44	0.00830
6(.138)	0.1380	40	0.01015
8(.164)	0.1640	36	0.01474
10(.190)	0.1900	32	0.0200
12(.216)	0.2160	28	0.0258
1/4	0.2500	28	0.0364
5/16	0.3125	24	0.0580
1/3	0.3750	24	0.0878
7/16	0.4375	20	0.1187
1/2	0.5000	20	0.1599
9/16	0.5625	18	0.203
5/8	0.6250	18	0.256
3/4	0.7500	16	0.373
7/8	0.8750	14	0.509
1	1.000	12	0.663
1 1/8	1.1250	12	0.856
1 1/4	1.2500	12	1.073
1 3/8	1.3750	12	1.315
1 1/2	1.5000	12	1.581

COARSE THREAD SERIES, UNC AND NC			
Sizes in.	**Basic Major Diameter in.**	**Threads per in.**	**Tensile Stress Area Sq. in.**
1(.073)	0.0730	64	0.000263
2(.086)	0.08660	56	0.00370
3(.099)	0.0990	48	0.00487
4(.112)	0.1120	40	0.00604
5(.125)	0.1250	40	0.00794
6(.138)	0.1380	32	0.00909
8(.164)	0.01640	32	0.0140
10(.190)	0.1900	24	0.0175
12(.216)	0.2160	24	0.0242
1/4	0.2500	20	0.0318
5/16	0.3125	18	0.0524
3/8	0.3750	16	0.0775
7/16	0.4375	14	0.1063
	0.5000	13	0.1419
9/16	0.5625	12	0.182
5/8	0.6250	11	0.226
3/4	0.7500	10	0.334
7/8	0.8750	9	0.462
1	1.0000	8	0.606
1 1/8	1.1250	7	0.763
1 1/4	1.2500	7	0.969
1 3/8	1.3750	6	1.133
1 1/2	1.5000	6	1.403
1 3/4	1.7500	5	1.90
2	2.0000	4 1/2	2.50
2 1/4	2.2500	4 1/2	3.25
2 1/2	2.5000	4	4.00
2 3/4	2.7500	4	4.93
3	3.0000	4	5.97
3 1/4	3.2500	4	7.10
3 1/2	3.5000	4	8.33
3 3/4	3.7500	4	9.66
4	4.0000	4	11.08

4-THREAD SERIES, 4UN			
Sizes Primary in.	**Secondary in.**	**Basic Major Diameter in.**	**Tensile Stress Area Sq. in.**
2 1/2		2.5000	4.00
	2 5/8	2.6250	4.45
2 3/4		2.7500	4.93
	2 7/8	2.8750	5.44
3		3.0000	5.97
	3 1/8	3.1250	6.52
3 1/4		3.2500	7.10
	3 3/8	3.3750	7.70
3 1/2		3.5000	8.33
	3 5/8	3.6250	9.00
3 3/4		3.7500	9.66
	3 7/8	3.8750	10.36
4		4.0000	11.08
	4 1/8	4.1250	11.83
4 1/4		4.2500	12.61
	4 3/8	4.3750	13.41
4 1/2		4.5000	14.23
	4 5/8	4.6250	15.1
4 3/4		4.7500	15.9
	4 7/8	4.8750	16.8
5		5.0000	17.8
	5 1/8	5.1250	18.7
5 1/4		5.2500	19.7
	5 3/8	5.3750	20.7
5 1/2		5.5000	21.7
	5 5/8	5.6250	22.7
5 3/4		5.7500	23.8
	5 7/8	5.8750	24.
6		6.0000	26.0

6-THREAD SERIES, 6UN			
Sizes Primary in.	**Secondary in.**	**Basic Major Diameter in.**	**Tensile Stress Area Sq. in.**
1 3/8		1.3750	1.1555
	1 7/16	1.4375	1.2777
1 1/2		1.5000	1.405
	1 9/16	1.5625	1.54
1 5/8		1.6250	1.68
	1 11/16	1.6875	1.83
1 3/4		1.7500	1.98
	1 13/16	1.8125	2.14
1 7/8		1.8750	2.30
	1 15/16	1.9375	2.47
2		2.0000	2.65
	2 1/8	2.1250	3.03
2 1/4		2.2500	3.42
	2 3/8	2.3750	3.85
2 1/2		2.5000	4.29
	2 5/8	2.6250	4.76
2 3/4		2.7500	5.26
	2 7/8	2.8750	5.78
3		3.0000	6.33
	3 1/8	3.1250	6.89
3 1/4		3.2500	7.49
	3 3/8	3.3750	8.11
3 1/2		3.5000	8.75
	3 5/8	3.6250	9.42
3 3/4		3.7500	10.11
	3 7/8	3.8750	10.83
4		4.0000	11.57
	4 1/8	4.1250	12.33
4 1/4		4.2500	13.12
	4 3/8	4.3750	13.94
4 1/2		4.5000	14.78
	4 5/8	4.6250	15.6
4 3/4		4.7500	16.5
	4 7/8	4.8750	17.5
5		5.0000	18.4
	5 1/8	5.1250	19.3
5 1/4		5.2500	20.3
	5 3/8	5.3750	21.3
5 1/2		5.5000	22.4
	5 5/8	5.6250	23.4
5 3/4		5.7500	24.5
	5 7/8	5.8750	25.6
6		6.0000	26.8

8-THREAD SERIES, 8UN			
Sizes Primary in.	**Secondary in.**	**Basic Major Diameter in.**	**Tensile Stress Area Sq. in.**
1		1.0000	0.606
	1 1/16	1.0625	0.695
1 1/8		1.1250	0.790
	1 3/16	1.1875	0.892
1 1/4		1.2500	1.000
	1 5/16	1.3125	1.114
1 3/8		1.3750	1.233
	1 7/16	1.4375	1.360
1 1/2		1.5000	1.492
	1 9/16	1.5625	1.63
1 5/8		1.6250	1.78
	1 11/16	1.6875	1.93
1 3/4		1.7500	2.08
	1 13/16	1.8125	2.25
1 7/8		1.8750	2.41
	1 15/16	1.9375	2.59
2		2.0000	2.77
	2 1/8	2.1250	3.15
2 1/4		2.2500	3.56
	2 3/8	2.3750	3.99
2 1/2		2.5000	4.44
	2 5/8	2.6250	4.92
2 3/4		2.7500	5.43
	2 7/8	2.8750	5.95
3		3.0000	6.51
	3 1/8	3.1250	7.08
3 1/4		3.2500	7.69
	3 3/8	3.3750	8.31
3 1/2		3.5000	8.96
	3 5/8	3.6250	9.64
3 3/4		3.7500	10.34
	3 7/8	3.8750	11.06
4		4.0000	11.81
	4 1/8	4.1250	12.59
4 1/4		4.2500	13.38
	4 3/8	4.3750	14.21
4 1/2		4.5000	15.1
	4 5/8	4.6250	15.9
4 3/4		4.7500	16.8
	4 7/8	4.8750	17.7
5		5.0000	18.7
	5 1/8	5.1250	19.7
5 1/4		5.2500	20.7
	5 3/8	5.3750	21.7
5 1/2		5.5000	22.7
	5 5/8	5.6250	23.8
5 3/4		5.7500	24.9
	5 7/8	5.8750	26.0
6		6.0000	27.1

12-THREAD SERIES, 12UN			
Sizes Primary in.	**Secondary in.**	**Basic Major Diameter in.**	**Tensile Stress Area Sq. in.**
9/16		0.5625	0.182
5/8		0.6250	0.232
	11/16	0.6875	0.289
3/4		0.7500	0.351
	13/16	0.8125	0.420
7/8		0.8750	0.495
	15/16	0.9375	0.576
1		1.0000	0.663
	1 1/16	1.0625	0.756
1 1/8		1.1250	0.856
	1 3/16	1.1875	0.961
1 1/4		1.2500	1.073
	1 5/16	1.3125	1.191
1 3/8		1.3750	1.315
	1 7/16	1.4375	1.445
1 1/2		1.5000	1.58
	1 9/16	1.5625	1.72
1 5/8		1.6250	1.87
	1 11/16	1.6875	2.03
1 3/4		1.7500	2.19
	1 13/16	1.8125	2.35
1 7/8		1.8750	2.53
	1 15/16	1.9375	2.71
2		2.0000	2.89
	2 1/8	2.1250	3.28
2 1/4		2.2500	3.69
	2 3/8	2.3750	4.13
2 1/2		2.5000	4.60
	2 5/8	2.6250	5.08
2 3/4		2.7500	5.59
	2 7/8	2.8750	6.13
3		3.0000	6.69
	3 1/8	3.1250	7.28
3 1/4		3.2500	7.89
	3 3/8	3.3750	8.52
3 1/2		3.5000	9.18
	3 5/8	3.6250	9.86
3 3/4		3.7500	10.57
	3 7/8	3.8750	11.30
4		4.0000	12.06
	4 1/8	4.1250	12.84
4 1/4		4.2500	13.65
	4 3/8	4.3750	14.48
4 1/2		4.5000	15.3
	4 5/8	4.6250	16.2
4 3/4		4.7500	17.1
	4 7/8	4.8750	18.0
5		5.0000	19.0
	5 1/8	5.1250	20.0
5 1/4		5.2500	21.0
	5 3/8	5.3750	22.0
5 1/2		5.5000	23.1
	5 5/8	5.6250	24.1
5 3/4		5.7500	25.2
	5 7/8	5.8750	26.4
6		6.0000	27.5

16-THREAD SERIES, 16UN			
Sizes Primary in.	**Secondary in.**	**Basic Major Diameter in.**	**Tensile Stress Area Sq. in.**
3/8		0.3750	0.0775
7/16		0.4375	0.1114
1/2		0.5000	0.151
9/16		0.5625	0.198
5/8		0.6250	0.250
	11/16	0.6875	0.308
3/4		0.7500	0.373
	13/16	0.8125	0.444
7/8		0.8750	0.521
	15/16	0.9375	0.604
1		1.0000	0.693
	1 1/16	1.0625	0.788
1 1/8		1.1250	0.889
	1 3/16	1.1875	0.997
1 1/4		1.2500	1.111
	1 5/16	1.3125	1.230
1 3/8		1.3750	1.356
	1 7/16	1.4375	1.488
1 1/2		1.5000	1.63
	1 9/16	1.5625	1.77
1 5/8		1.6250	1.92
	1 11/16	1.6875	2.08
1 3/4		1.7500	2.24
	1 13/16	1.8125	2.41
1 7/8		1.8750	2.58
	1 15/16	1.9375	2.77
2		2.0000	2.95
	2 1/8	2.1250	3.35
2 1/4		2.2500	3.76
	2 3/8	2.3750	4.21
2 1/2		2.5000	4.67
	2 5/8	2.6250	5.16
2 3/4		2.7500	5.68
	2 7/8	2.8750	6.22
3		3.0000	6.78
	3 1/8	3.1250	7.37
3 1/4		3.2500	7.99
	3 3/8	3.3750	8.63
3 1/2		3.5000	9.29
	3 5/8	3.6250	9.98
3 3/4		3.7500	10.69
	3 7/8	3.8750	11.43
4		4.0000	12.19
	4 1/8	4.1250	12.97
4 1/4		4.2500	13.78
	4 3/8	4.3750	14.62
4 1/2		4.5000	15.5
	4 5/8	4.6250	16.4
4 3/4		4.7500	17.3
	4 7/8	4.8750	18.2
5		5.0000	19.2
	5 1/8	5.1250	20.1
5 1/4		5.2500	21.1
	5 3/8	5.3750	22.2
5 1/2		5.5000	23.2
	5 5/8	5.6250	24.3
5 3/4		5.7500	25.4
	5 7/8	5.8750	26.5
6		6.0000	27.7

20-THREAD SERIES, 20UN			
Sizes Primary in.	**Secondary in.**	**Basic Major Diameter in.**	**Tensile Stress Area Sq. in.**
1/4		0.2500	0.0318
5/16		0.3125	0.0547
3/8		0.3750	0.0836
7/16		0.4375	0.1187
1/2		0.5000	0.160
9/16		0.5625	0.207
5/8		0.6250	0.261
	11/16	0.6875	0.320
3/4		0.7500	0.386
	13/16	0.8125	0.458
7/8		0.8750	0.536
	15/16	0.9375	0.620
1		1.0000	0.711
	1 1/16	1.0625	0.807
1 1/8		1.1250	0.910
	1 3/16	1.1875	1.018
1 1/4		1.2500	1.133
	1 5/16	1.3125	1.254
1 3/8		1.3750	1.382
	1 7/16	1.4375	1.51
1 1/2		1.5000	1.65
	1 9/16	1.5625	1.80
1 5/8		1.6250	1.95
	1 11/16	1.6875	2.11
1 3/4		1.7500	2.27
	1 13/16	1.8125	2.44
1 7/8		1.8750	2.62
	1 15/16	1.9375	2.80
2		2.0000	2.99
	2 1/8	2.1250	3.39
2 1/4		2.2500	3.81
	2 3/8	2.3750	4.25
2 1/2		2.5000	4.72
	2 5/8	2.6250	5.21
2 3/4		2.7500	5.73
	2 7/8	2.8750	6.27
3		3.0000	6.84

28-THREAD SERIES, 28UN			
Sizes Primary in.	**Secondary in.**	**Basic Major Diameter in.**	**Tensile Stress Area Sq. in.**
	12(.216)	0.2160	0.0258
1/4		0.2500	0.0364
5/16		0.3125	0.0606
3/8		0.3750	0.0909
7/16		0.4375	0.1274
1/2		0.5000	0.170
9/16		0.5625	0.219
5/8		0.6250	0.274
	11/16	0.6875	0.335
3/4		0.7500	0.402
	13/16	0.8125	0.475
7/8		0.8750	0.554
	15/16	0.9375	0.640
1		1.0000	0.732
	1 1/16	1.0625	0.830
1 1/8		1.1250	0.933
	1 3/16	1.1875	1.044
1 1/4		1.2500	1.160
	1 5/16	1.3125	1.282
1 3/8		1.3750	1.411
	1 7/16	1.4375	1.55
1 1/2		1.5000	1.69

32-THREAD SERIES, 32UN			
Sizes Primary in.	**Secondary in.**	**Basic Major Diameter in.**	**Tensile Stress Area Sq. in.**
6(.138)		0.1380	0.00909
8(.164)		0.1640	0.0140
10(.190)		0.1900	0.0200
	12(.216)	0.2160	0.0270
1/4		0.2500	0.0379
5/16		0.3125	0.0625
3/8		0.3750	0.0932
7/16		0.4375	0.1301
1/2		0.5000	0.173
9/16		0.5625	0.222
5/8		0.6250	0.278
	11/16	0.6875	0.339
3/4		0.7500	0.407
	13/16	0.8125	0.480
7/8		0.8750	0.560
	15/16	0.9375	0.646
1		1.0000	0.738

THIS PAGE WAS INTENTIONALLY LEFT BLANK.